

IMPOSSIBILITY OF TRANSIT IN ATLANTA: GPS-ENABLED REVEALED-DRIVE  
PREFERENCES AND MODELED TRANSIT ALTERNATIVES FOR COMMUTE  
ATLANTA PARTICIPANTS

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## SUMMARY

This thesis compared revealed-preference automobile morning work commute trip data from GPS-equipped instrumented vehicles of Commute Atlanta participants with transit commute alternatives identified in the regional planning model transit network. The Transit Capacity and Quality of Service Manual (TCQSM) travel time level of service (LOS) measure for transit was applied to these GPS automobile and modeled transit data. To quantify system-level transit availability, the TCQSM service coverage LOS was applied to the Atlanta region and Atlanta's transit service area LOS was calculated as C. Most of the commuters in this study would experience transit-auto travel time LOS of F. The analyses revealed that revealed automobile travel times were 45% shorter than the model-reported automobile travel time skims for the same origin and destination zones. Transit traces, calculated by manually tracing the trips from origin to destination via the most preferable transit mode, were about 24% longer than the minimum travel-demand-modeled transit skims. Only about 9% of commuters drove directly to work more than 95% of the time and only 6% of commuters left home within five minutes of their median departure time more than 95% of the time, indicating that the convenience and flexibility of the automobile is likely to be a significant element in these commute mode decisions. Commuters perceive the total transit trip time as between being 1.25 and 2.5 as long as the actual (modeled) time, and only about 25% of commuters could take transit without having to transfer. The calculated total cost of driving to work exceeded the cost of transit, but automobile operating costs alone did not exceed transit costs for about half the sample.

## **CHAPTER 1: INTRODUCTION**

The impetus of this study was to define the mode choice set for the work commute as a precursor for discrete choice analysis. Relevant costs for such analysis include monetary, time, and convenience costs. In addition, this study examines the structure of transit in the regional travel demand model from the standpoint of the individual rider. Granted, the travel demand planning model was designed for macroscopic analysis of network flows, but understanding the impact of the model structure on individual commutes can shed light on implications and limitations on use of the model. Capturing the automobile travel experience via the GPS revealed-preference trip data and treating transit through the lens of the travel demand model, this study also has implications for Atlanta's transit system itself.

This study focuses on travel time differences between auto and transit as a first-cut system level service measure of convenience. Though not wholly systemic, the analysis focuses on the level of service for individuals tracing paths through the transit system beyond the stop and route levels. In contrast with the Transit Capacity and Quality of Service Manual's (TCQSM) system-level service measure of transit availability, which is area-based, the results of this study provide implicit origin-destination measures of service coverage. The Manual's service coverage measure is then applied to Atlanta for comparison.

Figure 1 illustrates an example mode of the commute mode choices an individual might face. Trip characteristics such as trip time, travel distance, and any intermediate stopping locations can be gleaned from the actual driving path revealed by GPS. The transit choice is constructed using a minimum-cost transit path within the model. Table 1 indicates the transit trip would take almost 30 minutes to traverse just over three miles. This contrasts to the approximately 10-minute automobile travel time between the same locations. The existence of a transit option, travel time differential, number of transfers, waiting time, intermediate stopping, and schedule flexibility all impact the commuters evolution of the commute choice set.

Transit operators and MPOs do not currently have access to the GPS-based travel data employed in this study, but such data are expected to be available in the foreseeable future as vehicle-based and personal GPS-enabled devices continue to proliferate. Hence, the specific methodologies employed in this research and which are applied as performance measures can be used in the future. This investigation also sheds light on the efficacy and nuances of using such measures. Also, the results of the analyses lead to the conclusion that analysts should be very careful in using travel demand model skims for mode comparison and transit choice evaluation as the skims do not necessarily adequately reflect travel conditions from the passenger point of view.

The next chapter presents background information on commuting, travel demand modeling, and transit service measures. The third chapter discusses the regional growth, transportation infrastructure, commuting trends, and research efforts underway in the

study area, Atlanta, Georgia. Chapter provides a summary of the methodology of the thesis as a whole. Then, in Chapter five, the methodology pertaining to selecting the sample from the GPS automobile trip dataset is presented. Chapter six covers the transit trace modeling methodology, and chapter seven addresses the extraction of skims from the model output. The final chapter on methodology discusses factors associated with the various measures used in this study. Chapter nine presents the travel time comparisons, and Chapter ten explores trip chaining and convenience. The monetary costs are evaluated in Chapter eleven before Chapter twelve combines all the measures into a composite transit attractiveness. Chapter thirteen explores geographic aspects of the findings, such as the role of activity centers. To put the results of the individualized case analysis in perspective, chapter fourteen applies an accessibility measure to assess the regional transit service area. Finally, chapter fifteen presents the conclusions.

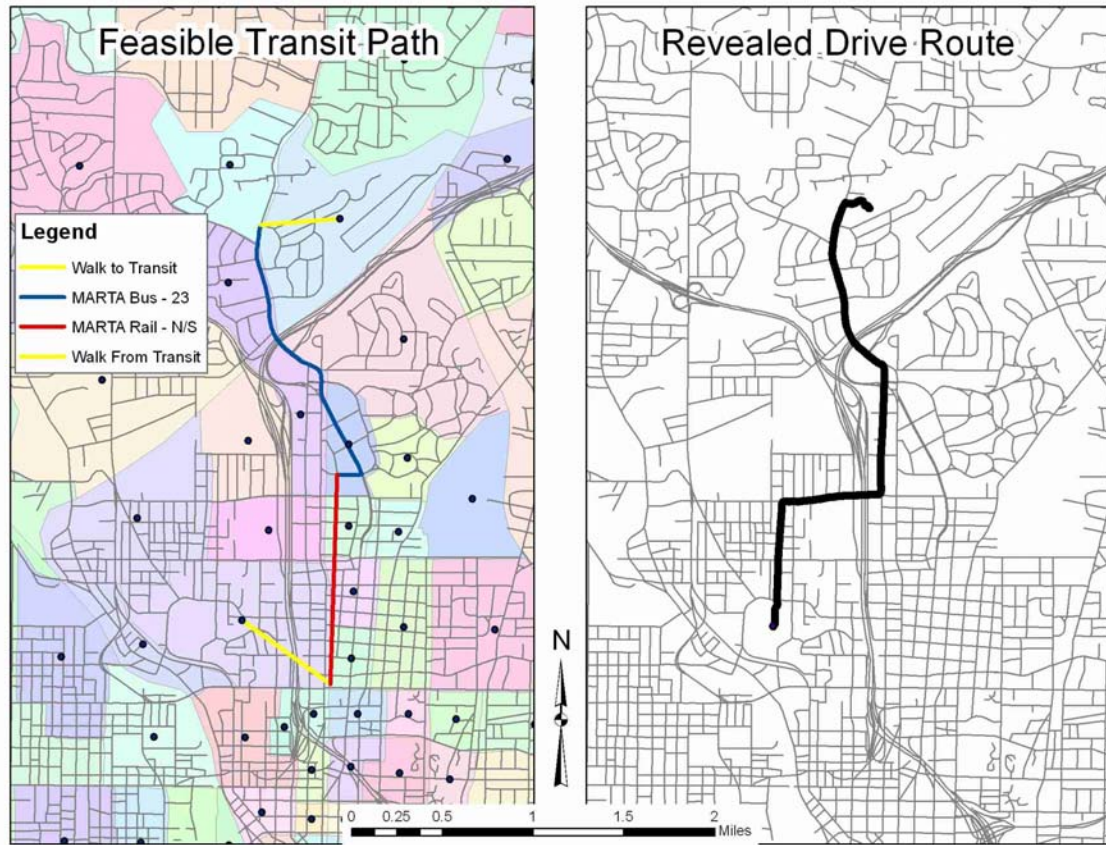


Figure 1: Example Choice Set

Table 1: Example Transit Trip Components

TAZ: 52-34	Time [min.]			Distance [mi.]	
	Wait	Travel	Total	Segment	Total
Walk to Transit		4.6	4.6	0.2	0.2
MARTA Local 23	5	6.0	15.6	1.5	1.7
MARTA Rail	2.5	3.0	21.1	1.2	2.9
Walk		5.6	26.7	0.2	3.2

## **CHAPTER 2: BACKGROUND**

For a commuter to choose to take transit to work, transit must be available, fast, convenient and affordable compared to other transport options. The commute transit journey consists of many elements, such as accessing, paying, waiting, transferring, and traveling, all of which affect the quality of the user's experience. Most of these aspects of the transit journey have parallels in the automobile journey. Modal comparison requires a synthesis of the relative strengths of transit and automobile in each area. The factors affecting and decision making processes involved in transportation are multiple and complex. Over the years, methods have been developed to represent these components of personal travel with travel demand models. Use of the models, in conjunction with direct observation of travel behavior, has enabled evaluation of the quality of transit service and the level of service for vehicular travel.

This thesis examines the feasibility for a group of Atlanta-area drivers to switch from their current automobile work commute mode to transit. The study is as much about methods (i.e., regional, aggregate travel demand modeling) as much as it is about the results (transit feasibility for individual). Beyond the common perception of the utility differential between transit and automobile in North American cities, substantial academic interest has been directed at studying urban commuting. The first section of this chapter explores the behavior underlying and a sampling of analytical approaches to commuting. The second section introduces the dominant method of analyzing urban travel behavior using travel demand models, with particular attention to how transit is

modeled. The third background section then presents two suggested methods for evaluating quality of transit service from the Transit Capacity and Quality of Service Manual. The TCQSM measures will be used in conjunction model transit output and GPS vehicle trip data to assess relative modal commute experience of Commute Atlanta participants.

### **Commuting: Underlying Behavior and Analytical Approaches**

Human behavior within the urban context is exceedingly complex, not only in terms of estimation of short-term, idiosyncratic point decisions (e.g., what particular route will a commuter take on any given day), but also with respect to more macroscopic issues of location and mode choice. Studies have attempted to quantify commuting through such measures as job-housing balance (Sultana 2002) and excess commuting (Kwan and Weber 2003). Jobs-housing balance measures the relative quantity of employment and residence within a given area. The jobs-housing measure is typically balanced at the metropolitan level but theoretically varies among smaller neighborhoods. The theory, then, is that the spatial separation between housing-rich and jobs-rich areas is a driving force of commuting. Excess commuting attempts to benchmark travel efficiency relative to an estimate theoretical minimum commute in which all commuters choose workplaces to minimize the regional cost of commuting (Horner 2004).

However, job-housing is an indirect assessment of travel, and “very few people are acting to minimize their journey to work by relocating either their home or workplace in the intraurban context” (Kwan and Weber 2003). As technology has evolved, and as travel speeds have increased, consumers have consistently taken advantage of the cost savings

by increasing travel distances to their maximum commute travel time budget, or travel time frontier (Banerjee, Ye, and Pendyala 2007).

Accessibility is another concept that addresses “potential for interaction in geographic space” (Horner 2004). Conventional accessibility measures primarily consider impedances of distance or time. In this light, accessibility is a characteristic of places, not individuals (Kwan and Weber 2003). Location theory and the monocentric city model utilize a conventional impedance of distance. However, increasingly with the emergence of the interstate highway system, information and communications technologies, and globalization, “distance as conventionally understood is of declining importance as an organizing principle of urban form and accessibility. ... Distance to employment centers and the geographic distribution of urban opportunities do not have a consistent relationship with individual accessibility” (Kwan and Weber 2003). Thus, commute trip time is more important than distance. Concerning traveler conception of time and distance, Kang et al. find “urban U.S. consumers may have better and more accessible knowledge of trip time than distance” for shopping trips (Kang, Herr, and Page 2003).

Emerging approaches attempt to improve upon previous urban commuting research by focusing on household decision making processes and taking into account individual activity schedules. For example, space-time prisms and potential path areas can provide a framework to view a person’s daily travel activities (Weber and Kwan 2002). The modeling manifestation of this individualized approach can be found in activity and tour-



based modeling. However, prior to delving into this arena, this thesis applies individual travel behavior data to more conventional modeling approaches to assess applications and limitations of the existing models.

### **Travel Demand Modeling – Zonal Accessibility**

Travel demand models (TDM) are macroscopic planning models that spatially aggregate and behaviorally simplify causal relationships to represent average travel behavior and predict volumes of trip flows and other large-scale measures. Instead of representing travel between specific point locations, such models typically utilize transportation analysis zones (TAZ) as the unit of analysis in the interest of computing efficiency and (relative) conceptual tractability.

A common model structure is the urban transportation modeling system, also known as the four-step travel demand model. The four-step model requires land use data input. Population and employment data for each TAZ are attributed to the TAZ centroid, an idealized point within the TAZ. Travel demand associated with the land use is typically generated according to logit or cross-classification models and the produced and attracted trips are distributed across the TAZs via a gravity model. The third step employs a logit model for mode choice, and the fourth step assigns the trips onto specific network travel paths. Centroid connectors provide synthetic paths between the centroids and the roadway network and enable travel to occur between TAZ centroids along the highway and transit network links.

The decision of what transportation mode to take to work depends on many factors including: 1) individual preferences, and 2) home and work locations relative to the available transportation infrastructure. Time is the dominant measure of impedance between locations, as it accounts for divergent modal speeds. Users also perceive time differently in different situations. For example, one minute waiting for a bus tends to be regarded differently than one minute riding on a moving bus. These factors need to be accounted for within the model. Transfers, time perception, and walk access are three areas discussed in detail below.

Not all time spent traveling is equal. Users perceive the passage of time differently depending on the trip segment type and mode. (Li, 2003) elaborates on various factors contributing to perceived travel time, where factors are grouped into: 1) commute characteristics (e.g., travel time), 2) journey episodes (access, wait, ride, transfer), 3) travel environments (comfort and entertainment), and 4) expectancy (e.g., reliability). In recognition of the many psychological factors at play in travel behavior and decision making, travel modeling typically applies mode factors to weight the relative time components. These factors are scaled relative to one minute of in-vehicle drive time. The resultant “perceived” time, in contrast to “actual” modeled time, can be used to choose the least cumbersome transit paths.

Mishalani et al. (2006) analyses perceived waiting time relative to the effect of real time bus arrival information feedback. The objective was to “model and quantify the difference between perceived and actual passenger waiting times at bus stops ... and to

investigate the effect of duration of the actual waiting time ... on this difference”

(Mishalani, McCord, and Wiirtz 2006). Analyzing results of a survey of 83 patrons of the campus bus service at Ohio State University, they found the perceived time exceeded the actual time by 0.84 minutes, but that for waits between three and 15 minutes the duration of the wait did not affect the degree of difference between perception and reality.<sup>1</sup> Another interesting finding was “a longer walking time [from egress to destination] produces a greater exaggeration in the perceived waiting time, while the presence of a time constraint brings the perceived waiting time closer to the actual time” (Mishalani, McCord, and Wiirtz 2006).

All else being equal, a transit trip requiring a transfer is less appealing than a transit trip that can be completed without a transfer. Guo and Wilson (2004) used onboard survey data for Boston, a spatial choice model, and GIS to quantify a transfer penalty equal a range of 2.3 to 21.4 minutes of walking time. That is, they found that transferring imposed a penalty valued at between 2.3 and 21.4 minutes in addition to the time spent transferring and waiting. Staff (1997) employed extensive manual transit path and impedance preparation with a method similar to that of the current study and also found transfers impose a penalty on the transit trip.

A brief survey of peer city models was conducted to get a comparative feel for the parameters used in the ARC model (ARC 2007). The model for the Washington D.C. area displayed similar characteristics to the Atlanta model (Milone 2004). Both assumed

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<sup>1</sup> The static difference of 0.84 minutes applied to the limits on the waiting time results in an equivalent mode factor ranging from around 1.06 to 1.28, which is much lower than the 2.5 typical of planning models.

a walking speed of three miles per hour and apply a weighting factor of 2.5 to walk access time to reflect that walking is assumed to be less desirable than driving on a minute-by-minute basis. D.C. also used a mode factor of one for premium transit. In contrast, the ARC model used a mode factor for premium transit of 0.7, which indicates 0.7 minutes on premium transit is perceived as the equivalent of one minute spent driving. Drive access time was weighted by a factor of 2.5 in the ARC model, whereas the D.C. model weighted one minute of drive access time as equal to one minute of in-vehicle time. The factor applied to both the wait for the initial transit mode and any waits during transferring was both 2.5 in both models. This heavily penalizes waiting time, resulting in one minute of waiting time being perceived as 2.5 minutes. Whereas the D.C. model did not differentiate between waiting for local and premium transit, the arc model reduces the premium wait factor to 1.75. These factors reflect assumptions about the psychology of travel in terms of evaluation of various trip components. However, it should be noted that these mode factors are often used in path building and not necessarily in impedance determination. The ARC mode factors were used to trace transit paths between home and work (see Section X).

### **Transit Capacity and Quality of Service Manual**

The Transit Capacity and Quality of Service Manual (TCQSM) (TRB 2003) serves as a fundamental reference for transit planning and is analogous to the established Highway Capacity Manual. The TCQSM defines quality of service as “the overall measured or perceived performance of transit service from the passenger’s point of view.” Quality transit service needs to be 1) available and 2) comfortable and convenient. The TCQSM suggests various measures of transit service from the passenger point of view. The fixed-

route quality of service measure of availability is service coverage, and the transit-auto travel time assesses the comfort and convenience of a fixed-route transit system. Each measure is expressed as level of service (LOS) letter score based on the numerical value.

The primary measure relevant to this study is the difference between transit and auto travel times. In addition to calculating the travel time LOS for the Commute Atlanta participants, the second measure applied in this study is the service coverage area, which provides a bigger-picture assessment of transit.

#### Difference in Travel Time LOS

LOS threshold values for the difference between transit and automobile travel time are given in Table 2. LOS A applies if transit is faster than automobile. The remaining LOS values progress in 15 minute increments, up to LOS F, for which transit would take more than an hour longer than automobile. The TCQSM suggest calculating the difference in travel time between zone pairs using a transportation planning model. Alternatively, for a manual method, it suggests the default transit time elements of 3 minute access time, 5 minute initial wait, and 3 minute egress time, in addition to the in-vehicle time. The manual also recommends adding three minutes onto automobile trips to account for parking and walking to the destination.

Table 2 TCQSM Fixed-Route Transit-Auto Travel Time LOS

LOS	Travel Time Difference (min)	Comments
A	≤0	Faster by transit than by automobile
B	1-15	About as fast by transit as by automobile
C	16-30	Tolerable for choice riders
D	31-45	Round-trip at least an hour longer by transit
E	46-60	Tedious for all riders; may be best possible in small cities
F	>60	Unacceptable to most riders

The travel time LOS will be applied to the GPS automobile trip data and the traced transit alternative (see Chapter 6), as well as to the model output skims (see Chapter 7).

### Service Coverage LOS

The TCQSM defines service coverage as a “measure of the area within walking distance of transit service.” Citing several studies, the TCQSM reports that on average 75 to 80 percent of passengers walk a quarter-mile or less to bus stops. Other studies have applied a half-mile buffer around rail stations. Applying these respective buffers and removing any walking-inaccessible areas yields the service coverage of the Atlanta transit system.

Transit service can only reasonably be expected to thrive in areas with enough potential ridership to support it. Transit supportive areas (TSA) contain sufficient population and/or employment density to justify hourly transit service. The service coverage LOS is calculated as the percentage of the TSA served (or within the service coverage area). The LOS values are outlined in Table 3.

Table 3 TCQSM Fixed-Route Service Coverage LOS

LOS	% TSA Covered	Comments
A	90.0-100.0%	Virtually all major origins & destinations served
B	80.0-89.9%	Most major origins & destinations served
C	70.0-79.9%	About ¾ of higher-density areas served
D	60.0-69.9%	About two-thirds of higher-density areas served
E	50.0-59.9%	At least ½ of the higher-density areas served
F	<50.0%	Less than ½ of higher-density areas served

As discussed in detail in Chapter 14 (Service Area and Transit-Supportive Area Determination), the analyses reported in this thesis will use a 0.25 mile buffer for bus and 0.50 mile buffer for rail.

Two particular studies have applied the TCQSM LOS measures to different metropolitan regions. Perk and Foreman (2003) synthesizes reports from Florida metropolitan planning organizations (MPOs) on the application of fixed-route transit measures from the first edition of the TCQSM. Differences in travel time were calculated between several major activity centers within each metropolitan region from travel demand model output and other sources. Service coverage was also calculated using GIS. One comment particularly relevant to the present study is:

... most of the participants in this evaluation experienced moderate to extreme difficulty in determining the travel times between the activity centers (models will measure between the centers of TAZs, not point-to-point) and expressed discontent that theoretically estimated travel demands and travel times were being compared with actual transit loads and travel times. (Perk and Foreman 2003)

Also, “the application of the measures to route segments between activity centers is not a complete representation of the transit service.” Perk and Foreman (2003) also mentioned the difficulty in interpreting the service coverage measure at a statewide level. Xin, et al. (2005) also analyzed flows between major activity centers in Waterloo, Ontario, Canada. They connected each activity center to the closest TAZ centroid. The travel time LOS was calculated using TCQSM manual assumptions and speed limit-derived travel speeds.

A wide range of LOS was obtained from LOS B to cases of LOS F where the travel time differential was greater than two hours. Service coverage LOS for the weekday AM peak was A, with about 91% of the TSA served.

These studies are relevant as previous applications of TCQSM measures in other regions. The variable and generally low travel time LOS and more favorable service area LOS from Xin et al. (2005) provide context for evaluating Atlanta's LOS identified herein. The methodological challenges alluded to by Perk and Foreman (2003) also play out in this thesis. Namely, the aggregated nature of regional models presents a challenge to the evaluating transit user experience between specific locations.

This chapter started by exploring some the factors underlying commuting behavior and analytical approaches used to study urban commuting. Travel demand modeling was then introduced to as a framework for representing travel and accessibility in terms of location. Finally, the TCQSM LOS measures were introduced in preparation for their application to the GPS and model data used in this study. Building on this foundation, the next section introduces background information specific to the Atlanta region



## **CHAPTER 3: ATLANTA CONTEXT**

### **Highway and Transit System**

Atlanta is framed by several radial Interstate highways converging on a downtown nexus. Interstate 75 spans from Florida to Michigan, while Interstate 85 extends from Alabama to Virginia, and Interstate 20 runs east-west from South Carolina to Texas. All three major roadways converge on the downtown and are contained by Interstate 285 (which is a high-volume beltway, or perimeter freeway).

The major transit service operator serving the city of Atlanta is the Metropolitan Atlanta Rapid Transit Authority (MARTA). MARTA is built on two major heavy rail lines that span Fulton and DeKalb counties: the north-south line and east-west line with one junction at Five Points. An extensive bus local network with 190 routes serves the two-county area, mainly as a feeder system for the rail. MARTA also operates a five of express routes. Clayton County Transit (CTran) provides five local bus routes in Clayton County, with a transfer point to MARTA rail at the airport. Local service is also provided by two northern counties, Cobb to the northwest and Gwinnett to the northeast. Cobb Community Transit (CCT) and Gwinnett County Transit (GCT) also operate express bus services down their respective interstate corridors, I-75 and I-85, to the Midtown and Downtown central business districts (CBDs). GCT operates five local routes and six express routes (and variants). CCT operates about a dozen local routes and about five express routes and their variations. The state, via the Georgia Regional Transportation Authority (GRTA), operates 24 express bus routes along most of the

major radial corridors<sup>2</sup>. Finally, several local shuttle systems service small areas such as university campuses or CBDs.

### **Regional Growth**

The core of the Atlanta region, the Atlanta Regional Development Center (RDC), consists of 10 member counties of the Atlanta Regional Commission. A 13-county region corresponded with the one-hour ozone non-attainment area and was used as a basis of older versions of the planning model. Since the phasing out of the one-hour standard, a new 20-county region reflects the eight-hour ozone non-attainment area and comprises the model extent for the region's newly developed integrated land use and transportation plan, Envision6. This study defines the Atlanta region as the 20-county area, which covers approximately 6,400 square miles.

The Atlanta RDC contained about 3.5 million people and about 2 million jobs in 2000. The 20-county region population was about 4.2 million and employment was about 2.3 million in 2000. The region continues to grow rapidly, with 20-county population projected to be 7 million and employment estimated at around 4 million by 2030 (ARC 2006).

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<sup>2</sup> There has been some modification of bus routes in recent years. This study is based on automobile commutes that were made in October 2004 but also uses the ARC 20-county 2005 base year network. Some of the traced transit routes were not in service in 2004 but have since come online. GRTA Xpress routes in particular have experienced high turnover. The goal of this study is to develop the methodology to construct hypothetical choice sets. That some routes in the model were not in service during the specific month from which the automobile data were observed is therefore not problematic. The study addresses base year transit feasibility.

Lacking any obvious geographic growth boundary, growth in the Atlanta region has capitalized on the ample available land and convenient highway system, resulting in the expansion of low-density residential development and the emergence of suburban commercial clusters. This geographic expansion accompanying growth in population and employment has been associated with longer commutes. Not only has growth occurred on the outskirts of the region, but central, often revitalized in-town areas have seen increases as well. In 2006, the Atlanta RDC surpassed a population of four million. Growth all across the region has placed increasing burden on the regional transportation system.

### **Commuting Trends**

Similar to many North American cities, the vast majority of Atlanta commuters drive to work alone. Commute travel is characterized by temporal concentration of trips within peak periods, which, given the automobile mode, strain the highway network. Commute travel times have increased with continued growth. In addition, the geographic characteristics of commute flows have also shifted over time.

According to ARC's 2001-2002 Household Travel Survey, the automobile was the mode of choice for 86 percent of all trips in the 13-county region. Atlanta's journey to work profile in 2000 revealed 89 percent automobile utilization<sup>3</sup>. Transit represented about a 3 percent mode share, which is less than the 4 percent who work at home.

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<sup>3</sup> The statistics in the remainder of this section are from Journey to Work **Q**, which is based on data contained in the Census Transportation Planning Package.

One of the most significant changes in the worker flow patterns in Atlanta has been the large increase in commuting between suburban residence and suburban work place (see Figure 2). In the year 2000, 53 percent of commutes were classified as suburban-to-suburban (compared to the 35 percent in 1970). Suburban-to-central comprised 20 percent of the year 2000 commutes, with central-to-central at 13 percent (compared to 29 percent in 1970). Central-to-suburban is 5 percent, and other patterns account for 9 percent.

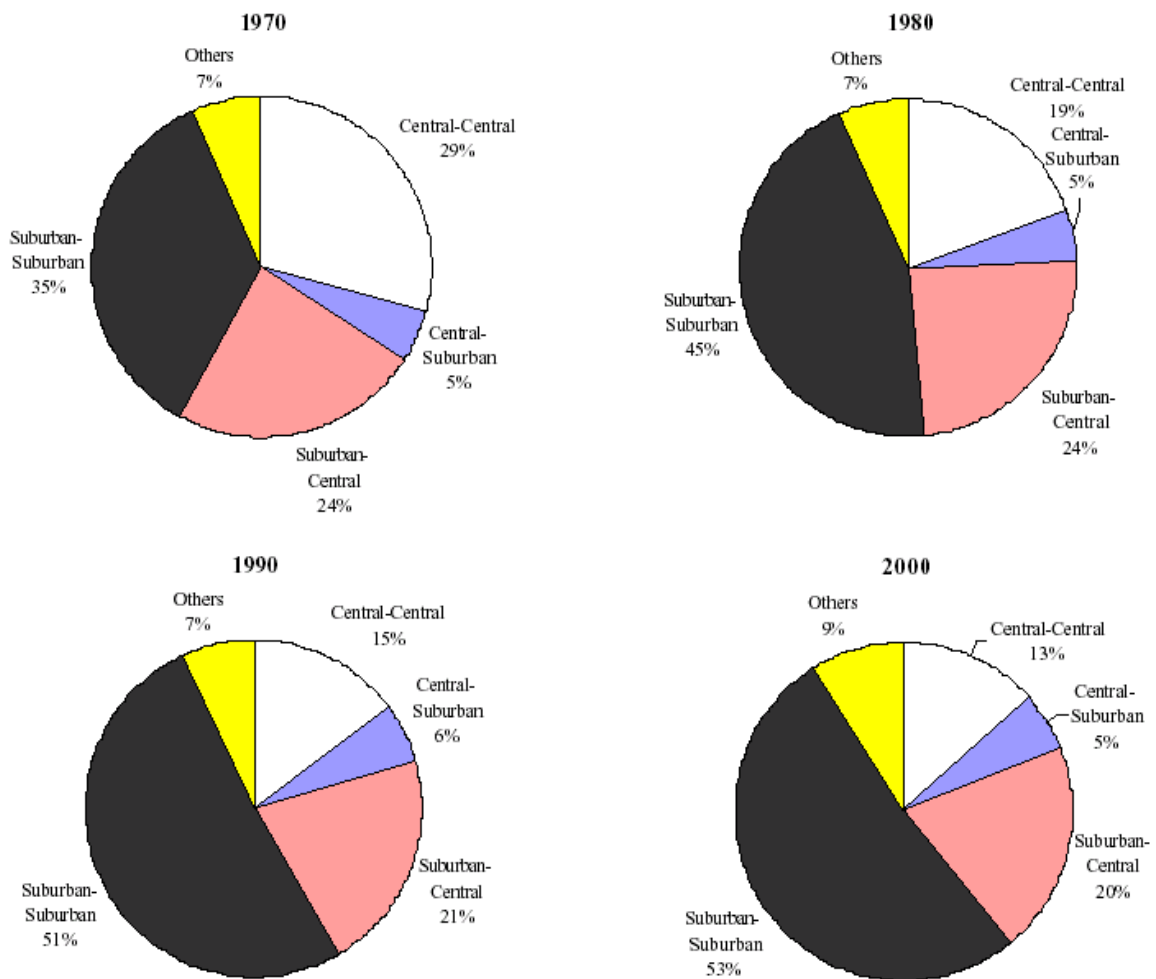


Figure 2 Atlanta Worker Flow by Area Type (Source: Journey to Work)

Suburban-suburban represents the dominant commute type with over half the year 20000 commutes. Suburban-central represent the next largest market segment (13%) is more or less served by the express bus system. Next, is central-central (13%), which is served by heavy rail and local bus service. Central-suburban, the reverse commutes, represent the smallest portion (five percent). Commute flows have changed since the early days of MARTA in the 1970's. Because transit tends to serve high density activity centers best, the trend of increasing suburb-to-suburb commuting does not bode well for transit's ability to serve region's commuting needs.

Commute travel times in Atlanta have been increasing due to population and worker growth, stable automobile mode choice, and limited roadway capacity. Between 1990 and 2000, workers in Atlanta experienced a 5.2 minute increase in travel time, compared to the 3.1 minutes national average. Figure 3 shows the commute time distribution of the Atlanta metropolitan statistical area (MSA) in Census 1990 and Census 2000. The percentage of workers who had commute times of less than 30 minutes decreased while the percentage of workers who had travel time longer than 45 minutes increased. Increasing commute times warrant further analysis of urban commuting in Atlanta, which this study undertakes.

The largest percent of workers depart home between 7:00 and 8:30 a.m. (see Figure 4). A comparison of departure time distributions for 1990 and 2000 provides evidence of peak spreading. There is a slight shift to earlier departures from 1990 to 2000.

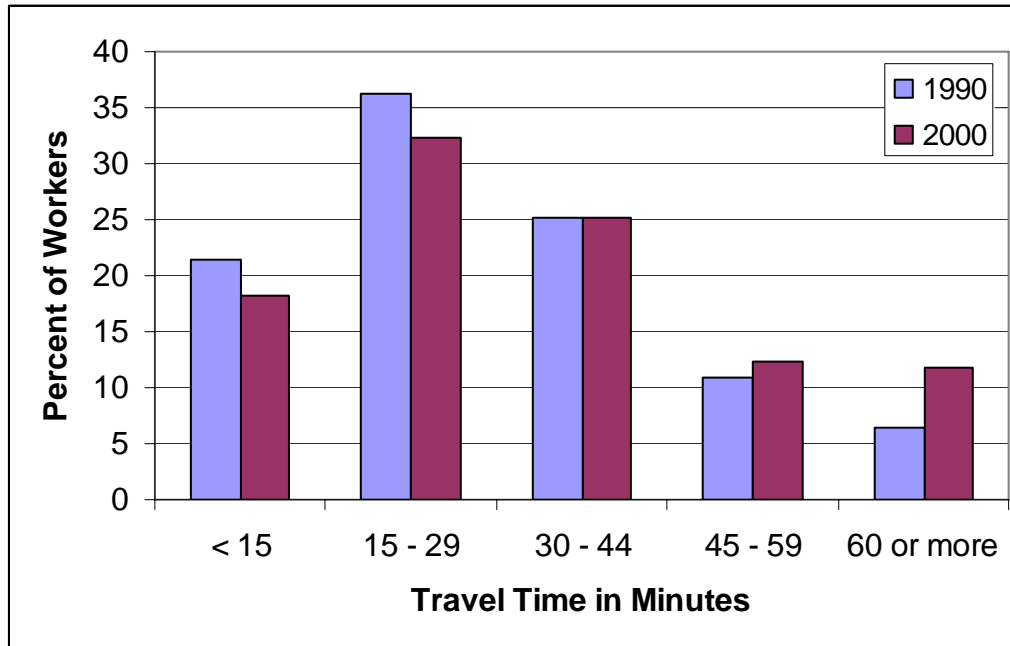


Figure 3 Atlanta MSA Commute Time Distribution (Source: Journey to Work)

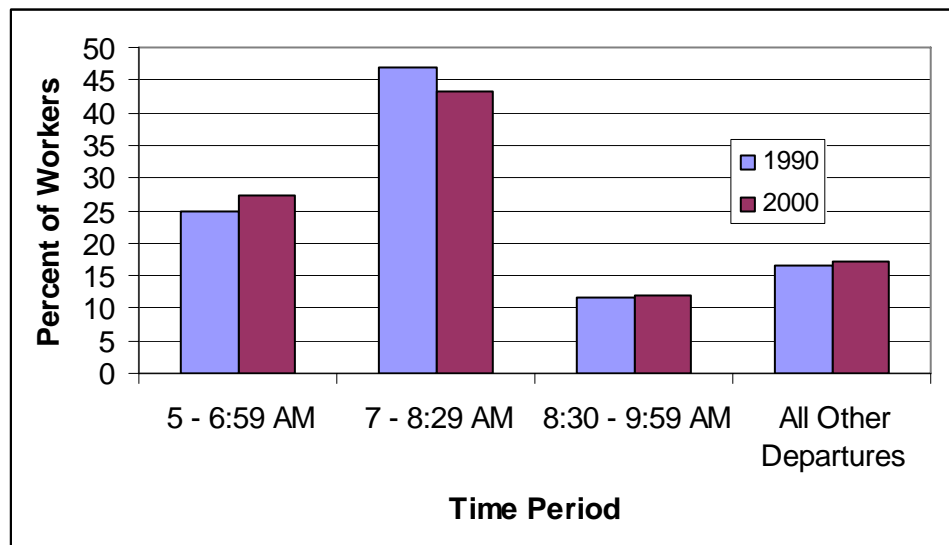


Figure 4 Atlanta MSA Morning Commute Departure Time (Source: Journey to Work)

## **Commute Atlanta**

The Commute Atlanta research is designed to assess the effects of converting fixed automotive operating costs into mileage-based and congestion-based operating costs. Over the past two and half years, the Commute Atlanta project has collected detailed information for more than 1.8 million vehicle trips. Second-by-second vehicle speed and position are recorded for every trip. Travel diaries and employer commute options surveys are also collected from each participating household and its employer(s). This rich dataset provides research opportunities in a wide range of transportation related areas including planning, safety, operation and air quality, etc. The specific sample of Commute Atlanta trips used in this thesis represents home-to-work commute trips in the morning 6-10AM peak.

## **Atlanta Travel Demand Model**

ARC's 20-county base year model was used in this study. The model contains 2024 TAZ's and more than 50,000 links, encompassing more than 30,000 lane miles. Figure 5 shows the TAZ polygons, TAZ centroids, GIS transit shapes, and driving links for park-and-ride. The model is built using TP+ scripting and is run within the Cube Voyager framework. The full model contains many different modules intended for different purposes. The present study used a subset of the model elements. Specifically, the transit network was used in conjunction with a TP+ function to obtain the costs of traveling from one TAZ to another (see Chapter 6 Transit Traces Methodology). Additionally, ARC-compiled output tables representing similar costs were used in the analysis (see Chapter 7 Model Skims Methodology).

The next chapters will outline the methodology employed to trace the model transit network, read the model skim impedances between zones, and characterize the automobile GPS commutes.

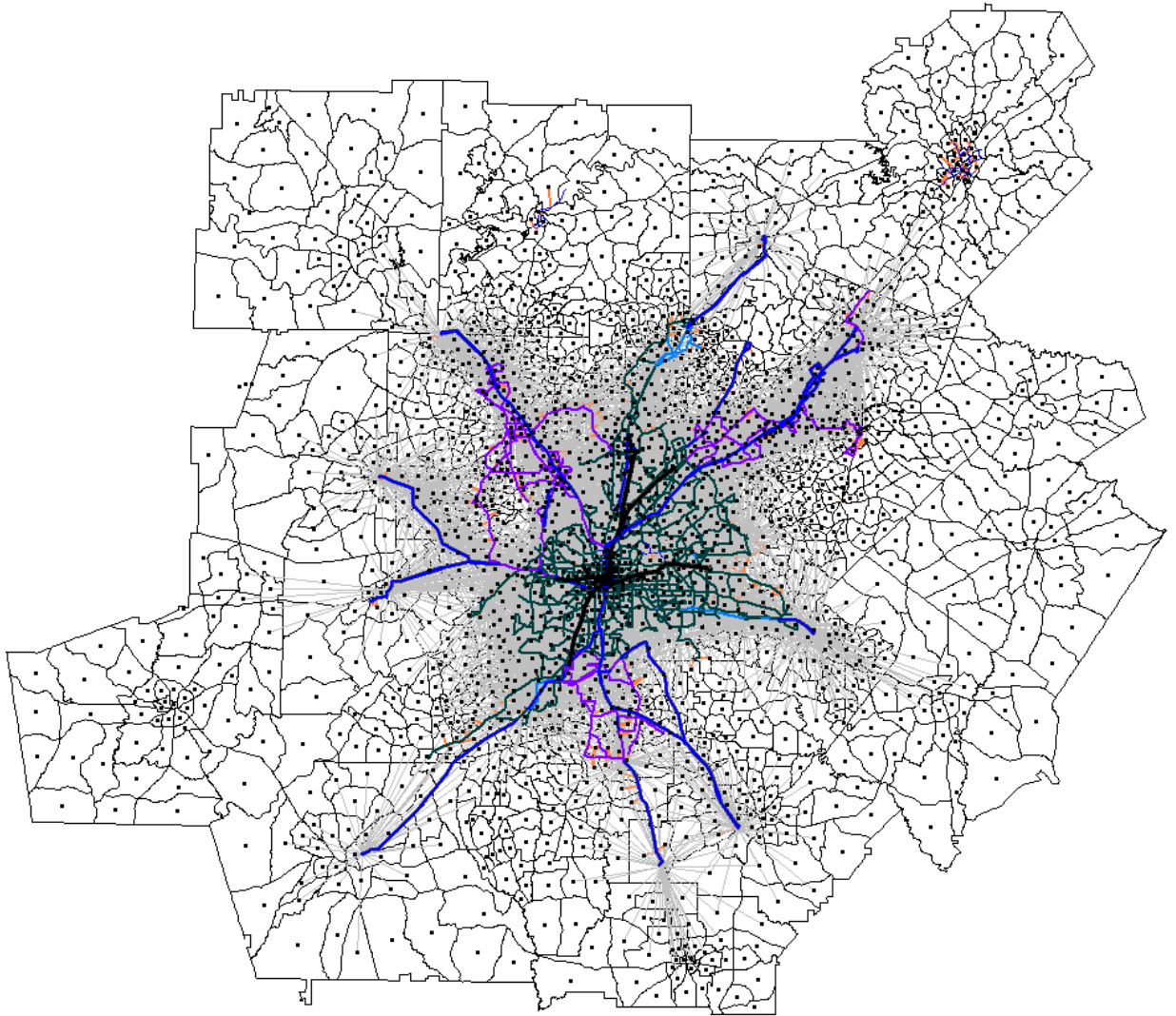


Figure 5 Model TAZ and GIS Transit Routes



## **CHAPTER 4: SUMMARY OF METHODOLOGY**

Traditional studies of mode choice often survey transit riders to obtain transit trip data and run the regional travel demand model to obtain characteristics associated with automobile choice. In contrast, this study draws on the unique and rich Commute Atlanta dataset to obtain revealed-preference automobile commute trips, for which components of the regional model are used to generate associated feasible transit paths. The primary thread of analysis, therefore, draws on the GPS-based automobile data and modeled transit data.

The automobile trips were made in October 2004 by participants of the Commute Atlanta study. See Chapter 2 (Background) for background on the Commute Atlanta project, which provided the automobile trip data used in this study. From the raw trip data set, trips were identified as commute trips if they originated at the geocoded home location or the most frequent trip end within 24-hour periods and if they terminated at the geocoded work location or the most frequent trip destination during the morning peak. To be included in this study, each vehicle needed to make at least 10 commute trips in the month. Automobile trip duration, trip chaining, and schedule consistency variables were aggregated for use in the analysis. That is, as long as they reported to work, the analyses ignored whether they stopped for coffee or undertook some other activity along the way. Chapter 5 (Automobile Trip and Sample Selection) describes the construction of the sample set in more detail.

The transit option analysis was conducted by tracing each home and work location back to the transportation analysis zone (TAZ) that contained the point. The transit path between the zones was then generated using components of the ARC 20-county 2005 base year model. The transit lines, roadway network, access support links, and portions of code were input into a TP+ TRNBUILD application within Citilabs Cube software. The Trace command was used to “trace” the transit network from home TAZ to work TAZ for each commute in the sample. The time, distance, and number of segments of each access, transit, and transfer/wait mode were retained for analysis. Chapter 6 (Transit Traces Methodology) covers the specific sequence of analysis necessary to construct the transit choice alternatives. Figure 6 shows the sources and flows of data used in this study.

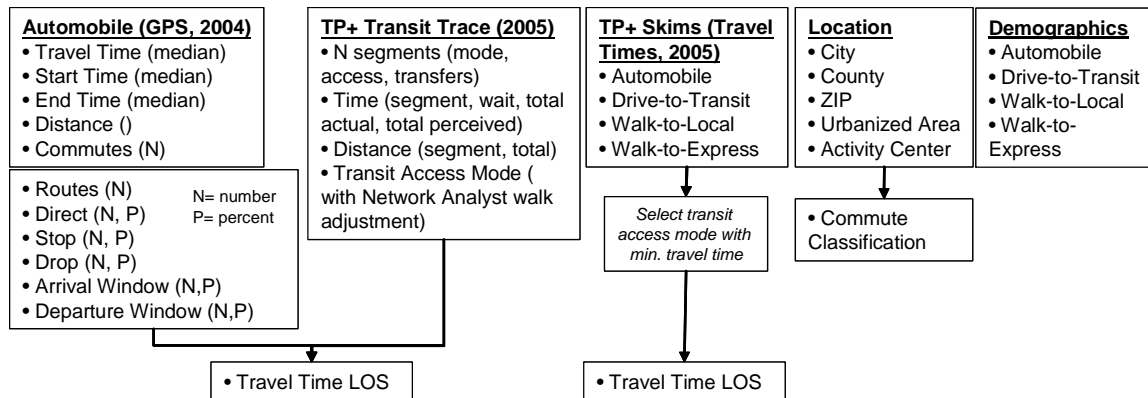


Figure 6 Data Flow

A secondary analysis compared the automobile and transit travel times between zones by another method. The use of model “skim” output tables from regional travel demand models to assess the modal level of service is suggested by the Transit Capacity and Quality of Service Manual. This method selected the relevant zone-to-zone travel times

stratified by mode and transit access sub-mode. Chapter 6 (Transit Skims Methodology) presents the automobile and transit skims in more detail.

Once the travel time and mode characteristic data were assembled, transit and automobile variables were paired to form various measures for modal comparison. Specific methodologies relevant to these measures are presented in Chapter 8 (Measures). The final methodology chapter addresses the geographic analysis, which involved the identification of commute classifications.

## **CHAPTER 5: AUTOMOBILE TRIP AND SAMPLE SELECTION**

The automobile personal vehicle activity data were obtained from a sample of morning commutes by participants of the Commute Atlanta project. This section addresses the methodologies to derive commute level information from the second-by-second GPS-based revealed automobile commutes, including commute start and end time, origin and destination locations, travel time and distance, and travel itineraries.

Due to the signal acquisition delay under cold start conditions (it normally takes the GPS unit up to 60 seconds to start acquiring valid position information), trip start positions provided by the GPS under cold start may not be the real start positions. Since this study records all the vehicle activities during the study period, and trips take place sequentially, the previous trip's end position is used as the current trip's start position, assuming vehicles did not move with the engine is turned off. A trip's end position is generally accurate since the GPS unit is usually fully functional when a trip ends (the exceptions occurring when a vehicle enters a parking garage or other GPS-shadowed location).

A series of procedures was developed to differentiate the morning commute activities from the other vehicle activities during the day. A series of trips consisting of a first trip starting at home, last trip ending at the work place, and all intermediate trips that take place during the morning commute time-period (6-10 AM) on a weekday<sup>4</sup> were considered a single morning journey-to-work.

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<sup>4</sup> Vehicle activities that occurred on public holidays are excluded from the dataset.

The household travel diary survey effort collected the home address of each household and the work address of each worker in the household, which were then geo-coded to produce latitude and longitude coordinates for each location. However, it was noted that the geo-coded household survey addresses sometimes did not agree with the vehicles' observed garaged locations, due to potential inaccuracies and/or discrepancies in the geo-coded locations. To solve this problem, the commute journeys were sampled based on origin/destination in a multi-tiered process. Commute cases were identified by using geocoded locations or any of the top three most visited locations.

In the first step, commute journeys were obtained from the Commute Atlanta database by selecting journeys that started within 500 feet of the participant's geo-coded home location and ended within 1000 feet of the participant's geo-coded work location. The second step was to select journeys based on start/end location frequency. Trips that started within 500 feet of the 24-hour most frequent trip end (considered the home garage location) and that ended within 1000 feet of the most/second/third most frequent trip end in the morning peak period (considered the work location) and are repeated more than 10 days per month are selected.

Using this method, 2082 morning commute journeys made by 136 vehicles were identified in October 2004<sup>5</sup>. This represents only about a quarter of the over 400 instrumented vehicles in the study fleet at the time.

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<sup>5</sup> The month of October 2004 was selected because it provided larger fleet and more work days (large sample and no major holidays).

The results of each step of the process, as defined above, are:

- Geocoded address: 41
- First frequency: 79
- Second frequency: 14
- Third frequency: 2

This provided a total of 136 home to work commute cases.

Once the potential sample of home-to-work commute journeys was compiled, the distributions of trip duration, distance, start time, number of commute routes, number of chained trips, number of chain segments, and duration of chain stays were calculated as another potential indication of convenience (i.e. activities might have to be foregone had a transit choice been selected). Specific methods implemented to calculate these variables can be found in (Li, 2004). Demographic variables were also available from the travel survey of Commute Atlanta participants and were included in the final dataset (see Appendix B Demographic Characteristics of the Sample).

## CHAPTER 6: TRANSIT TRACES METHODOLOGY

The transit choice was investigated primarily through a hybrid method utilizing the regional planning travel demand model, supplemented with various GIS tools. An alternate method might have been to create a multimodal ArcGIS network dataset,<sup>6</sup> but this work was beyond the scope of the analysis and undertaking such a resource-intensive effort was not necessary to obtain accurate information required for comparative analysis. In addition, transit alternatives are often constructed manually by referencing routes, schedules, etc. The interest in this study, however, was to develop a method that could be replicated for large numbers of potential cases, which would become quite burdensome manually. Furthermore, by generating the individualized transit paths with the TDM model and supplemental tools, this study provides unique insight into the application of the model itself. The method employed systematically assesses selected elements of Atlanta's transit system and synthesizes insights on the transit system not otherwise possible with a piecemeal manual study.

Macroscopic planning models are rarely applied to the travel paths of individuals, which might be better suited to simulation or case studies. However, the multimodal, line combining, transfer, wait, and perceived time capabilities of the model were particularly appealing for this study. It was possible to run the individual travelers through the transit

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<sup>6</sup> In theory transit GIS centerline, fare information, and schedule time tables would be available in such a dataset, but the compilation and verification of such a network dataset was deemed beyond the scope of this study and left for others as a general model improvement activity.

network to obtain an individualized picture of the various components of the transit choice.

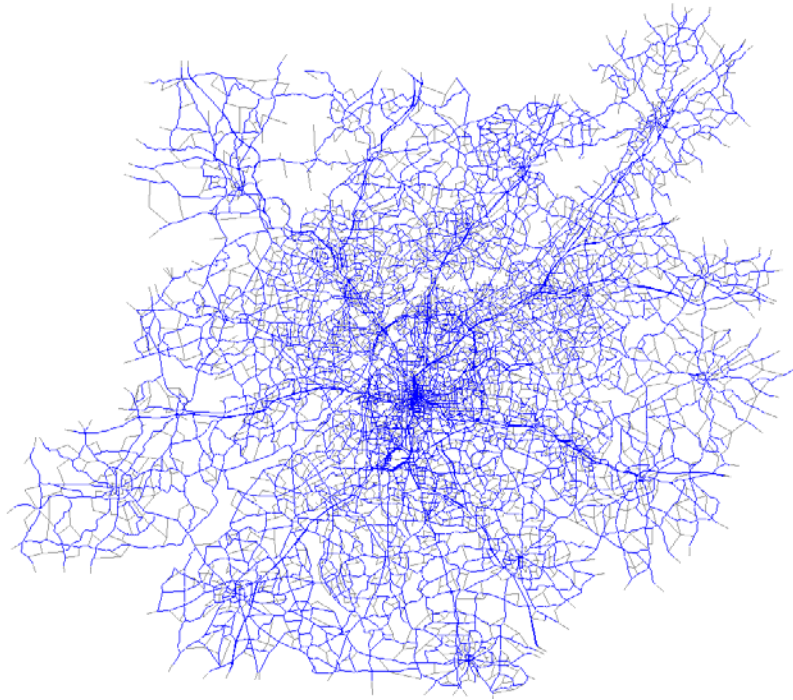
Another issue was to select the optimal level of geographic representation. The planning model currently uses a simplified geography of straight line links between network shape points which are placed in geographically accurate locations, while the links themselves often deviate from the real-world path. In the end, the geographic deviation between the model network and the GIS centerline network was deemed to be within acceptable limits, with worst-case displacements of certain segments of only up to a few hundred feet. The analytical gain of being able to utilize the transit capabilities of the model with the geographic strengths of GIS was deemed to exceed any loss associated with any slight incompatibility between the two.

The GIS tools included Network Analyst, used in looking at walk access to transit. Additional applications included using the model stop locations to calculate the transit service area (see Chapter 14 Service Area and Transit-Supportive Area Determination). Finally, the geographic attributes of the home and work locations were assessed using spatial join procedures.

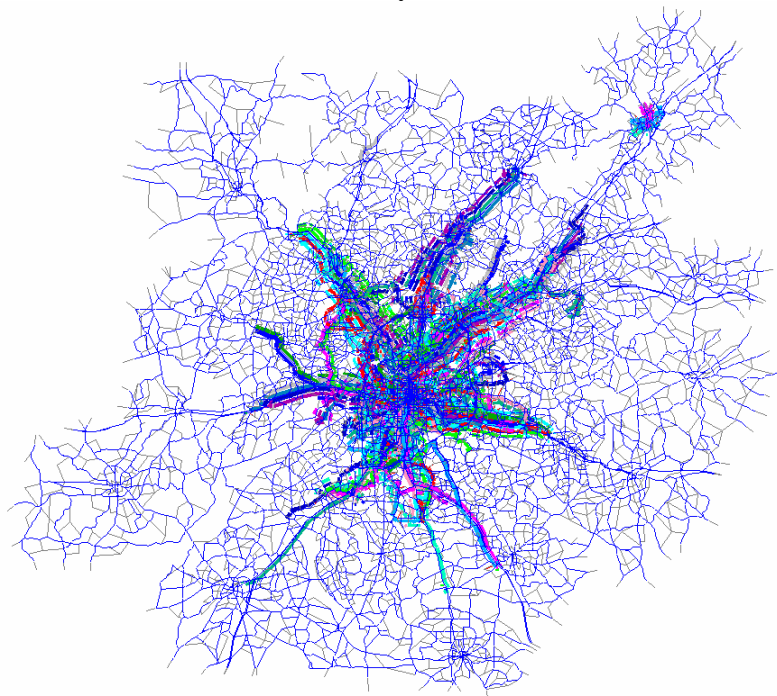
Components of the ARC 20-county 2005 base year model including transit lines, roadway network, access support links, and portions of code were input into a TP+ TRNBUILD application within Citilabs Cube software. The transit and roadway networks are shown in Figure 7. The roadways included the 2005 AM network



appropriate for transit. This network contained a bus time variable, which indicated the average time required for a transit bus to traverse the link. ARC's bus speed model generated the bus times by accounting for such factors as dwell time, stop frequency, cruise speed, and congestion effects (ARC 2007).



a) Roadway Network



b) Transit Network

Figure 7 TP+ Model Network

The Cube Trace Command was used to “trace” the transit network from home TAZ to work TAZ for each commute in the sample. The model built shortest time transit paths based on perceived time through the use of mode factors, which accounted for the relative value of time of various modes and transit trip segments (see Chapter 2 Background). The modeling framework treats wait times as half the headway, which is a reasonable approximation if passenger arrivals are random and service is on schedule<sup>7</sup> (Staff 1997).

Default transit modeling parameters were adopted from the ARC travel demand model. Specifically, support link transfer controls, line combining, perceived time factors, transfer wait factors, and transfer penalties from the AM skim building section of code were used. Wait factors included 2.5 for bus and 1.75 for rail. Perceived time factors included 2.5 for bus, 0.7 for rail, and 2.5 for transfers. Transfer penalties were 1 minute for premium-to-premium transfers, 3 minutes for transfers to/from premium, and 5 minutes for non-premium to non-premium transfers. See Chapter 2 (Background) for a description of the mode factors and the ARC Model Users Guide for more information (ARC 2007).

The transit paths are built based on perceived time.

This study constrains the choice set to contain only the most competitive transit route because the goal is to demonstrate transit feasibility in a sparse transit environment relative to automobile, not to assess internal competitions among transit modes. A tiered

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<sup>7</sup> Maximum wait times could have been specified, but this would have required assuming route synchronization and consistent on-time performance.

process was employed to selectively obtain the most competitive transit alternative for each case. The tiers were based on the transit access sub mode: walk-to-transit (WTT), park-and-ride (PNR), and drive-to-transit (DTT). See Figure 8 for a conceptual representation of selection hierarchy applied in this study and the associated model transit support links in Figure 9.

In assessing transit feasibility, it was assumed the most appealing or lowest impedance transit alternative would merely require a walk-to-transit. The model's park-and-ride support links (see Figure 9) were built to attract trips from selected TAZ with directional bias. For example, a PNR lot in the northwest would be more likely to attract more trips from the northwest than southeast. In contrast, drive-to-transit support links were built to connect every zone centroid to transit. PNR is more likely to produce a logical transit alternative than DTT. Therefore, the commute cases were first examined for possible WTT transit paths, then for PNR transit alternatives, and finally DTT transit choices.

The TAZ's associated with the home and work locations of the 136 cases resulting from the automobile commute trip selection process were obtained by spatial joins (see Chapter 13 Impacts of Activity Centers and other Geographic Implications). Four cases contained at least one trip end outside the 20-county planning area. These external trips were therefore considered beyond scope of and were excluded from this analysis, yielding a sample of 132 cases. Utilization of the model also excluded intrazonal trips, or cases with the home and work locations within the same TAZ. Intrazonal trips cannot be traced in the model. The time, distance, and number of segments of each access, transit,

and transfer/wait mode were retained for analysis. The following sections address the methodologies specific to each transit access sub-mode.

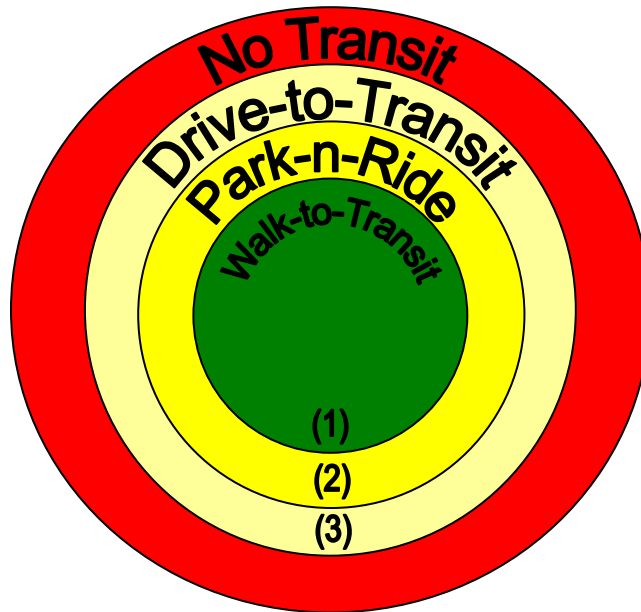


Figure 8 Tiered Process for Selecting Transit Choice

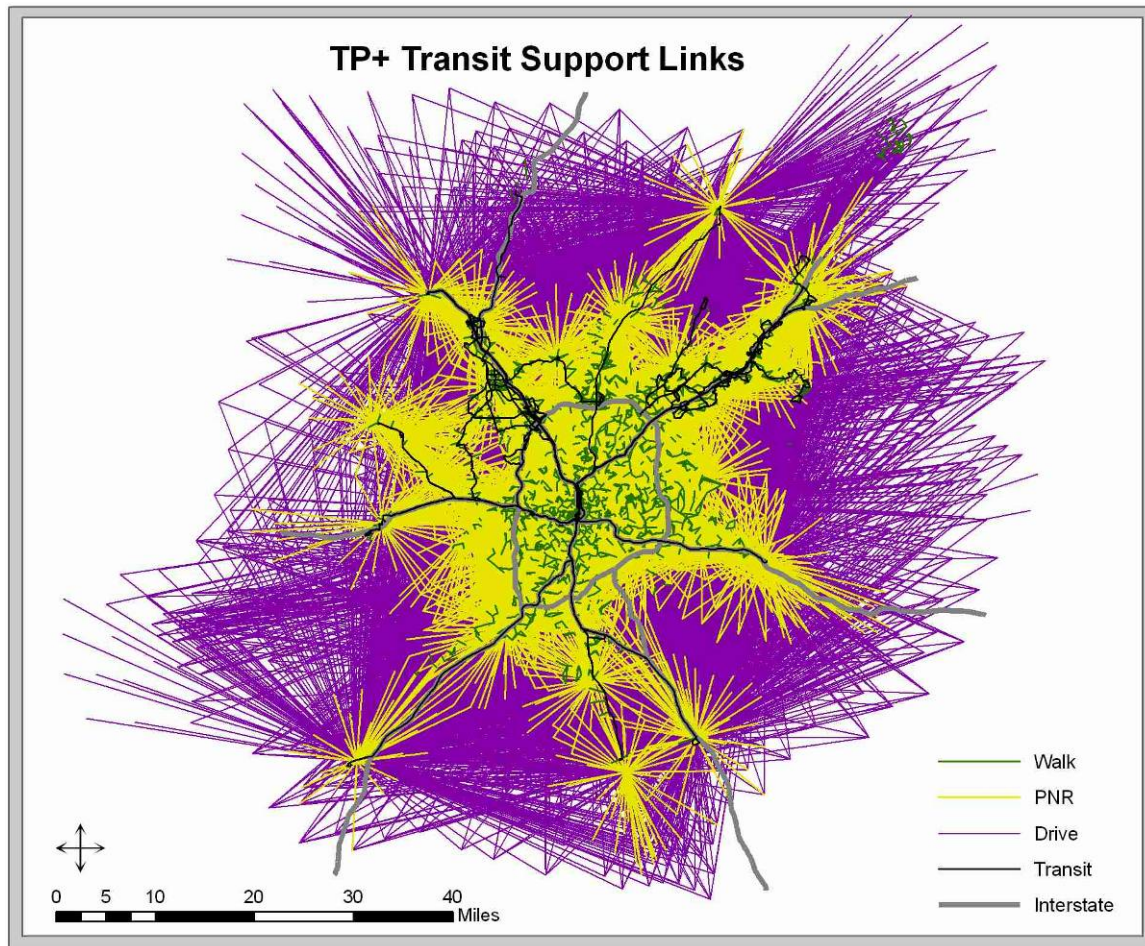


Figure 9 Transit Support Links<sup>8</sup>

### Walk Access

The first stage in assembling the transit traces was to see which cases were the most accessible to transit, that is, which were within walking distance. An initial TP+ transit trace model run of the 132 cases identified 34 (26%) walk-to-transit cases. The initial trace run ensured the selection of walk mode by not considering PNR or DDT support links. The reasonableness of the initial TP+ reported traces needed to be verified relative

<sup>8</sup> Note: GIS transit route and Interstate shapes are displayed along with the model support links for ease of visualization

to the likely user experience of the individual commuters. The method selected to examine the initial WTT cases was to use the ArcGIS Network Analyst tool to compare the TP-plus reported walk access impedance with the actual network distance for each case. Two unreasonable WTT cases did not conform to the average characteristics of the number transit accessible portion of the zone (see the case study in the next section) and were therefore excluded. The walk support link impedances were updated with the appropriate individualized network distance, and the model was re-run to retrace the transit path.

Chapter 3 (Atlanta Context) discusses the ARC model structure. Review of the initial model results yielded much shorter walk times than might reasonably be expected. This motivated the exploration into the model's treatment of walk access to transit and the application of Network Analyst. The goal was to compensate for the error associated with the model's zonal aggregation relative to the individual point locations. The trip needed to "return" from the centroid to the specific destination. The initial thought was that traversing the walk support links to the centroid might result in unrealistically large impedances for commuters with destinations closer to the transit stop and small impedances for commuters with destinations farther from the transit stop.

A method was developed to explore these transit stop node, TAZ centroid, and actual destination relationships using vector analysis, and this method is described in the following section.

### Interlude: Case Study of Example Walk

This case study focuses on the test case illustrated in the introduction, which was not associated with an Actual Commute Atlanta participant. It was noted the walk time assigned to the walk segment from the North Avenue MARTA rail station to Georgia Tech of two minutes appeared unrealistically small<sup>9</sup>. Personal experience indicated the walk to the destination, which is relatively close to the centroid, albeit a little farther from the station, averaged 11 minutes of walk time with approximately two minutes of intersection delay. Figure 10 presents the case, with utilized walk support links shown in yellow on the left. The right side of the figure gives the model roadway network in blue, rail network in black, walk support links in orange, destinations in blue shapes, and actual origin and destination locations in green circles.

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<sup>9</sup> To get from the rail station to the TAZ centroid, three walking links were actually reported, with a total time of about five minutes. The two intermediate walking links were required to get from the station to the road network and traverse a short segment of roadway to reach the “stop node” end of the centroid connector itself. The five minutes is still a shorter time than would be expected. However, the primary focus of this case study is on the impedance of the connector itself, which was two minutes.



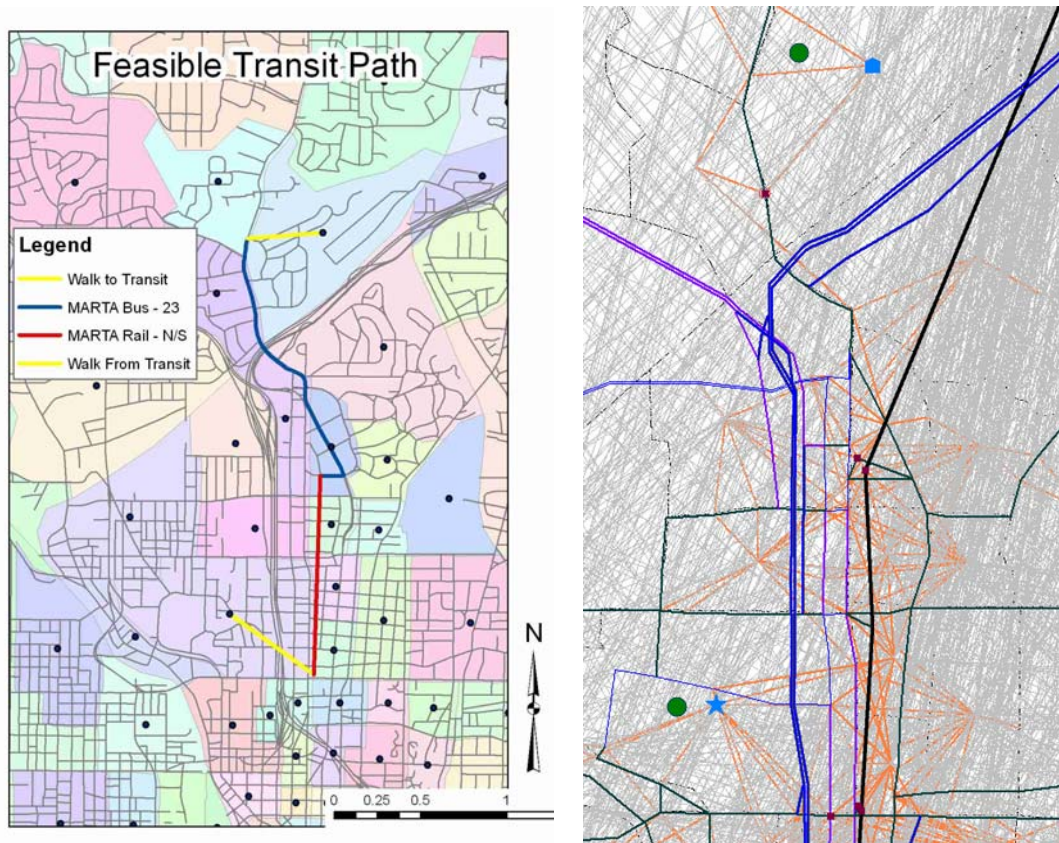


Figure 10 Case Study of Walk Access (Egress)

Figure 11 examines the detailed relationship among the node, centroid<sup>10</sup>, and destination locations at the work end of the trip. Applying the three mile per hour walk speed to the distances between the points, the actual walk times were determined along the connector itself, between the node and the destination, and the difference between the destination and centroid. An algorithm could be developed to compensate for the discrepancy between the centroid and actual destination by utilizing the direct distance from node to destination and/or components of the difference.

<sup>10</sup> The terms “centroid connector” and “walk support link” are used interchangeably in this section. A walk support link may or may not coincide with the centroid connector. Regardless, what is important is the the distance (and therefore time) between the transit stop node and the zone centroid.

In performing these analyses, and after contacting the ARC modeling staff, it was revealed that the ARC model framework does not actually assign walk support link impedances based on actual link distance, but rather uses an identical value for all walk support links for any given zone (see Appendix A Walk Access Discussion ). This explained the extreme discrepancy observed and necessitated the implementation of an alternative analytical approach.

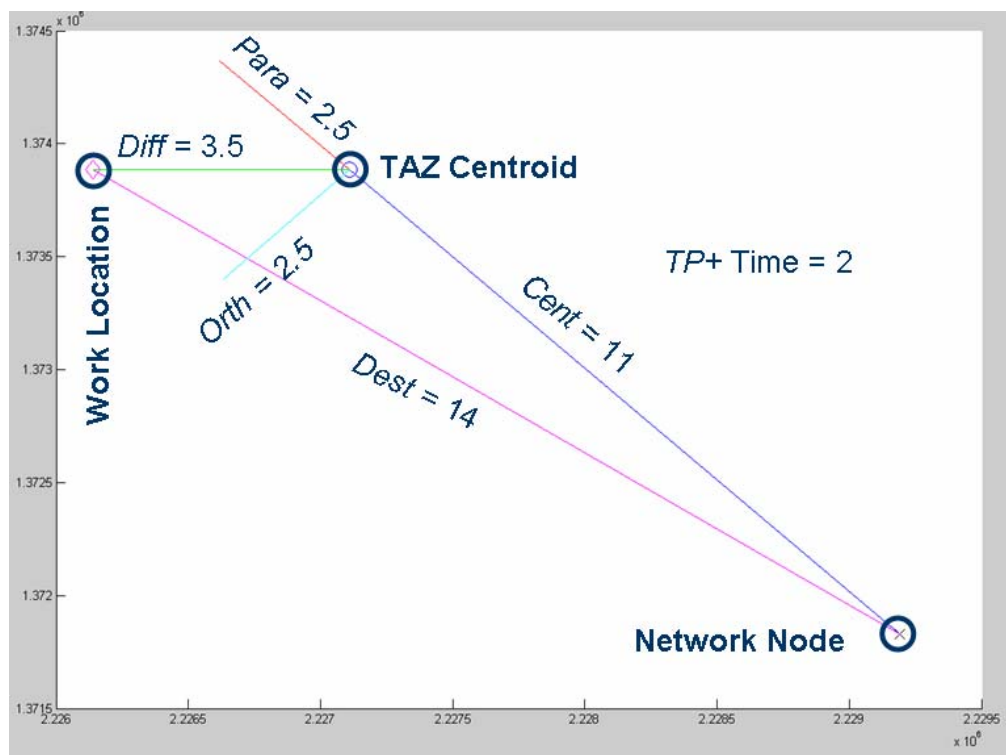


Figure 11 Bringing the Traveler from the Centroid back to the Actual Destination  
[minutes]

### Network Analyst

Given the support link impedance was not related to actual geographic distance between the transit stop and the zone centroid, support link impedances would need to be

corrected. Retaining the model's usefulness in dealing with the transit trip once the traveler has left the centroid, the individual user experience of the specific cases needed to be assessed. Taking the stop node reported in the initial trace as a given<sup>11</sup>, Network Analyst created a shortest-path route from the transit stop to the actual trip end locations, on both the home and work ends for each of the 34 WTT cases. Because a regional sidewalk dataset was not available, the street centerlines were assumed to represent walkable paths.

The network path distance exceeded the coded link impedance for over 85% of the walk paths inspected (68 total paths, one access and one egress for each commute). The average walk impedance of traced walk links used in the model was about 0.22 miles for the home end and about 0.18 for the work end of the trip, whereas the average network path required a 1.05 mile<sup>12</sup> walk on the home end and 0.39 mile walk on the work end of the trip.

One case involved no direct transit mode, utilizing one walk access link to a transit node, then another walk access link to the destination. A direct walk was calculated using Network Analyst. This result was paired with the intrazonal results (see Chapter 13 Impacts of Activity Centers and other Geographic Implications).

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<sup>11</sup> This relies on the network structure of the model, including zonal characteristics (size, shape, orientation, etc.), inclusion of stops, and creation of walk support links. The identified stop is an artifact of all of these factors within the aggregate model structure and may not represent the best, most logical, or most likely to be user-selected choice. There are conceivable cases where a transit-accessible point location within a TAZ is denied a transit choice because the TAZ lacks walk support links. The converse could also be true, where despite a TAZ possessing walk support links, a user would not reasonably be able to walk to transit to/from an specific point location within the TAZ. The former is beyond the scope of this work, but found two cases of the latter, discussed below.

<sup>12</sup> This excludes the two cases, described in the next section, that were excluded from the sample.

*Interlude: Too Far to Walk*

In two of the initial WTT cases, although the centroids were connected to transit, because the actual work locations were located in distant and inaccessible portions of the TAZs, the only realistic access mode for the return trip would be drive-to-transit. These two cases were excluded from further walk analysis, and were relegated to PNR or DTT for processing. Further analysis indicated these zones actually did not contain PNR support links and the DTT traces turned out to be unreasonable. Hence, for these two cases initially identified as WTT through the standard modeling routines, there was no real practical transit alternative.

The most extreme case is displayed in Figure 12 . Severe deficiency in street network connectivity in the neighborhood resulted in a very circuitous route traversing 7.63 miles to walk to transit from home (see Figure 12 a). This contrasts with the walk support link distance of 0.2 miles. Obviously, the 7.63 miles would be an unreasonably long walk. Given access to PNR support link, TP+ traces a drive to a PNR lot near Cobb Galleria, followed by a short bus trip (see intermediate locations as green stars in Figure 12 b). However, this would also be inconsistent with reasonable travel behavior; if the commuter were to drive to the PNR lot, they may as well continue driving all the way to work. Splitting the TAZ into separate zones could reduce this effect.

A second case found a 3.55 mile network distance relative to a coded distance of 0.27 miles. This time, when a PNR transit trace was attempted, TP+ reported a drive to a PNR lot, followed immediately with a walk to destination. No actual transit mode was

involved in the trace as there is a lack of local service coverage. Therefore, this case was excluded from the final dataset.

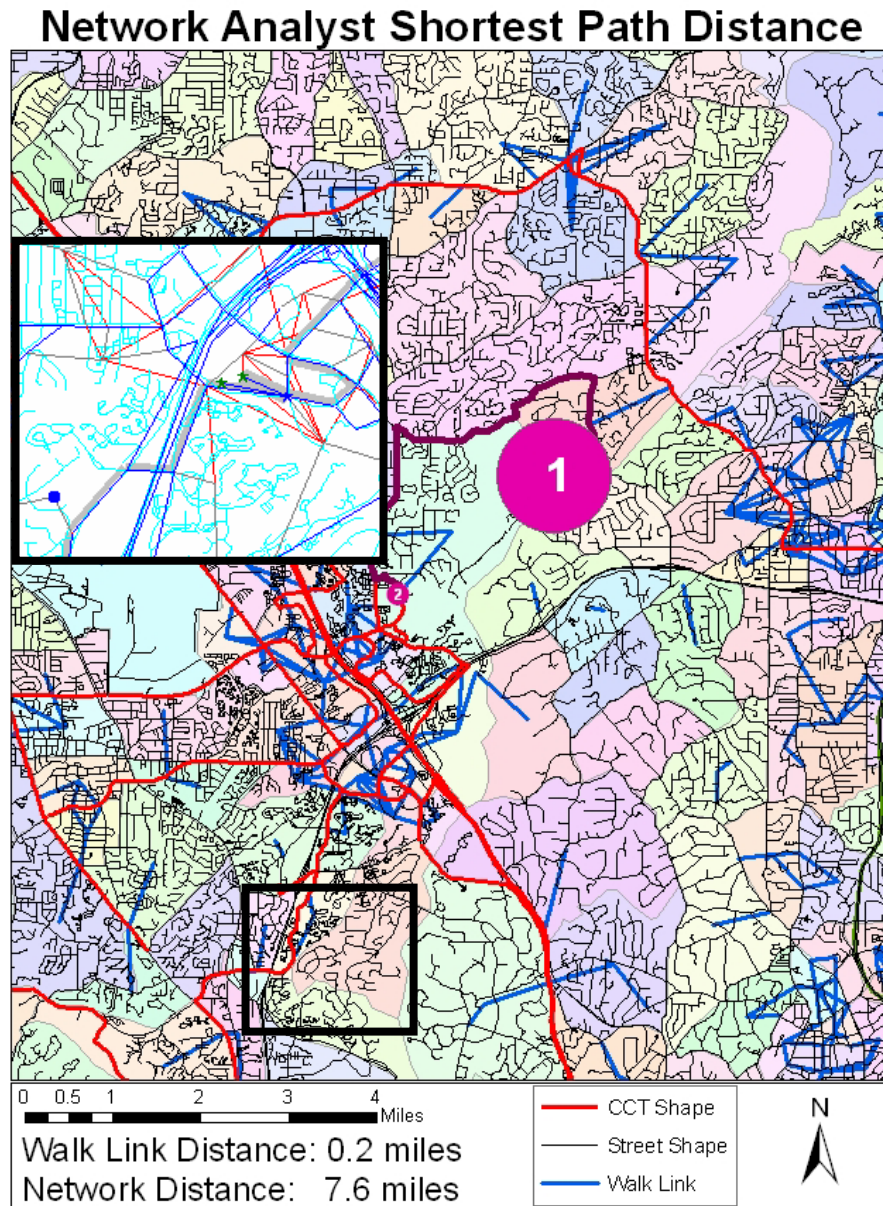


Figure 12 Walk Case Study - Network Analyst Shortest Path Distance to Transit from Home [Inset: PNR Lot, Local Bus, and Work Centroid]

Having excluded these two WTT cases as unreasonable, the remaining 32 WTT cases were ready to be retraced with updated walk impedance values.

#### Retracing with Updated Impedances

The analysis assumed that a three mile per hour walking speed (as used in the ARC model) was applied to the Network Analyst walking distances to obtain an updated walk time, or impedance. The revised impedance was then assigned to the same walk support link indicated in the initial trace, for each case. Because in some cases the new impedance was significantly larger than the value it replaced and therefore larger than any and all other walk support links for the same TAZ, all non-utilized walk support links were suppressed. By assigning an impedance of 9999 minutes for such links, the TP+ traces, which find the shortest cost paths, were forced to utilize the walk support links of interest. See footnote 11 for a discussion on potential limitations of this approach.

Because the modeling framework entailed customization of the walk support links for each case, only one trip end could be located within each TAZ. Given the potential sample of 136 home and work pairs across the region with more than 2,000 zones, this did not prove too problematic. Examination of the TAZ pairs in the set of 136 cases revealed that of all home TAZ and work TAZ, only four pairs were shared. Therefore, the reprocessing of these walk-to-transit traces was done in two runs, with one case of each pair separated into the second run.

Of 34 home locations, 30 (88%) had longer network paths to transit than the coded support link impedance value. For the 34 work locations, 28 (82%) also needed to have

the impedance value increased. The average increase in the walk impedance from home was about one mile, and the walk from transit to work was increased by about a quarter mile.

The underestimate of walk to transit impedance in the model might not be as drastic as might first be implied by these findings. The argument might be made that the 2.5 mode factor for walk access might account for, in addition to the temporal burden of the walking experience relative to driving, a buffer or safety factor that might indirectly account for the difference between network distance and the support link impedance. This is not to justify the model methodology, but rather to qualify the extent to which the trends might be apparent.

Note the analysis of walk access to/from transit was limited to the walk-to-transit cases (presented in the above section); walk support links on PNR and DTT trips were not updated. Original impedances were retained, which, as this walk examination reveals, underestimate the impedance for most cases. A likely result is a biasing of the results to tend to overestimate transit accessibility, especially since walk on the work end of a trip is the determining factor in transit accessibility. If one cannot walk to work from transit, then transit will not be selected. Also note, however, the degree of divergence between model-coded and network-derived impedances was more significant at the home than the work end of the trip. Therefore, the default walk transit egress impedance values were retained for the remainder of the analysis.



## **Drive Access**

### Park-and-Ride

Once the WTT cases were identified, the second step in assembling the transit traces was to trace the transit network again for the remaining cases, this time including park and ride support links in addition to the walk support links, which are of course necessary in getting from transit to destination. Of the 91 remaining cases, 43 had transit alternatives utilizing PNR support links. Though detailed treatment of the walk links was not necessary as noted above, the home and work centroids, transit access node from PNR lot, transit egress stop nodes, and transfer stop nodes were examined for each PNR case to determine the reasonableness of the trip.

Twenty-seven of the 43 PNR transit paths were reasonable choices. Specifically, they were directionally consistent, and the drive segment was not disproportionate to transit segments. On the contrary, 16 of the choices were unreasonable. Often the drive access segment of the trip was much longer than the transit segment(s), which in the limit would lead to the decision to just go ahead and drive all the way to the destination instead of bothering with transit (assuming that parking costs do not play a significant role in mode choice, which in Atlanta they generally do not). Another example of an unreasonable choice would be a drive outbound to PNR for inbound trip. Although this type of circuitous route is quite prevalent in getting from one place to another by transit in the Atlanta region, a logical filter was applied to the PNR (and DTT) trips, given the competition between drive-to-work and drive-to-transit, whereas the choice is more



straightforward given walk-to-transit (the assumption was made that if a walk-to-transit choice exists, it would trump any PNR or DTT choice).

Implications of the drive access investigation include lack of suburban local transit service and transverse transit connectivity between suburban centers. Furthermore, lack of adequate connectivity of suburban local-to-express was identified. For example, the total transit trip time of many relatively short distance suburban local trips were inflated by PNR lots not being connected to local buses. Instead, the PNR lots appeared to service only the express buses, which necessitated an extremely long-distance trip into and out of Midtown or Downtown. This does not appear to be a result of a direct transfer exclusion of drive access to local bus in the model. Investigating the model behavior in this respect could constitute an area of future work. Effort should also be made to ensure transit operators minimize the burden of transfers among PNR lots, local bus, and express bus services.

#### Drive-to-Transit

The third stage was to utilize the drive-to-transit support links (while retaining the walk support links but disabling the PNR support links). Drive-to-transit traces were found for 12 of the last 48 cases (25% of input, 9% of total). Though many of these paths were quite burdensome, only two of the 12 were excluded outright. Similar to many of the PNR traces, many of the DTT traces involved long drive access segments to get to transit. However, the majority of the DTT alternatives were not so completely inconsistent with common sense so as to warrant exclusion – the transit alternative was simply time-consuming, which would be reflected in the LOS comparison. One of the two excluded

DTT cases involved a drive to PNR lot (via DTT access mode), then walk to destination, which, similar to the too far to walk example, involved no actual transit mode. The second excluded case is shown in Figure 13. The PNR lot and the destination are virtually equidistant<sup>13</sup> to the origin and the transit segment provides virtually no directional advantage (contrasted to a long distance, radial commute, where a commuter would drive a portion of the trip to the PNR lot, then take transit into town). The trace does not represent a viable transit alternative any rational actor would consider.

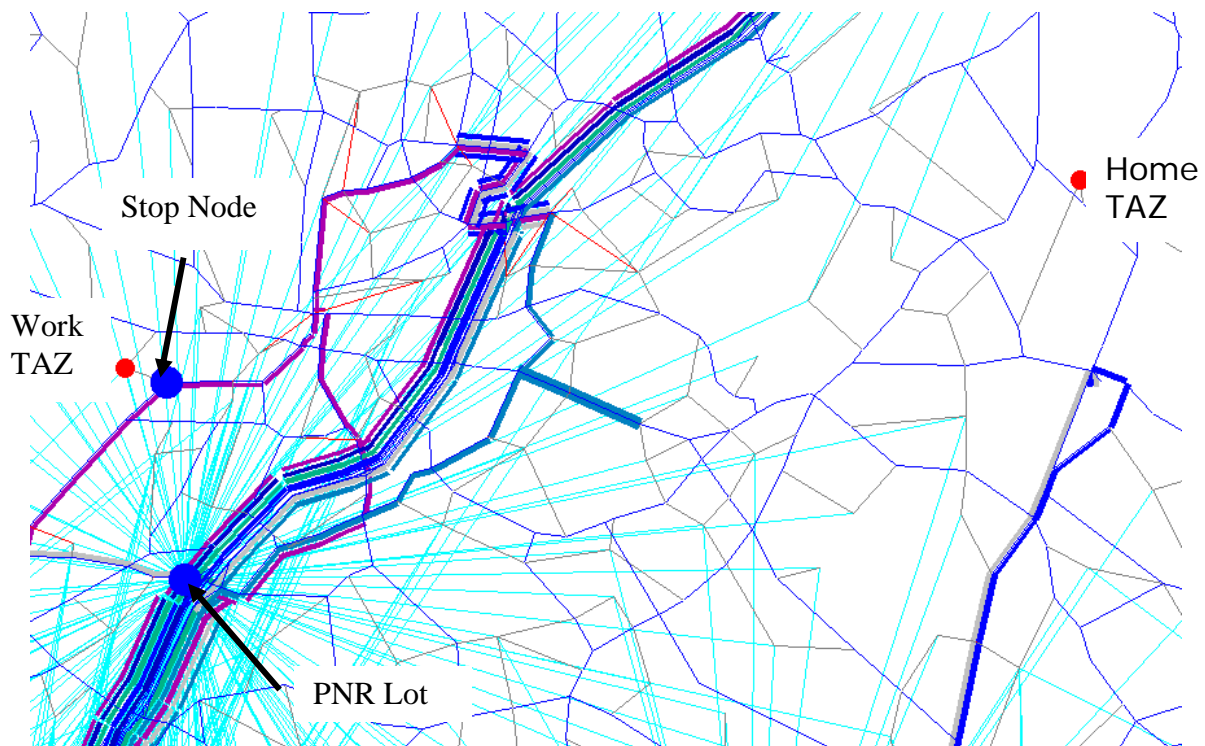


Figure 13 Excluded DTT Case<sup>14</sup>

<sup>13</sup> This assumes the model roadway network is coded with impedances that reasonably reflect the graphical appearance of distance, which may or may not be the case.

<sup>14</sup> Note that only point locations shown are model network nodes and zone centroids.

## **Final Trace Sample Composition**

Data cleaning and analysis following the initial WTT, PNR, and DTT traces slightly modified the sample totals. The excluded cases described above were screened from the sample. In the process of analysis, several commute cases initially thought to occur within the same zone (intrazonal trips) were found to have relatively reasonable direct walk commute alternatives. Along with the initially-reported direct walk case, three intrazonal cases had home and work locations within the same zone. Because these intrazonal cases involved home and work locations relatively close together and yet were not respectable within the model structure, direct walk alternatives were explored. A fifth case was found to span two adjacent zones, for which a direct walk would be feasible. Network Analyst was run between the locations to assess commute impedance for all five of these direct walk cases.

Accounting for the four external, five direct walk, and 20 excluded cases, Figure 14 presents the final trace sample composition. The excluded cases consisted of the two WTT, 16 PNR, and two DTT cases. No transit alternative was available for cases 36 cases that failed to return any results for WTT, PNR, or DTT. The excluded cases were grouped with the no transit group because no reasonable transit trace was identified. Both the cases without an identified transit trace are treated in a case study and the direct walk results are assessed in Chapter 14 (Impact of Activity Centers and other Geographic Implications).

The final sample of 71 cases is shown by access mode in Figure 15. The results presented in this paper are based on this sample unless stated otherwise.

In conjunction with the difference in travel time between GPS revealed-preference automobile trip and TP+ trace modeled transit alternative, the automobile and transit skim tables directly output from the ARC model were used to calculate a parallel measure.

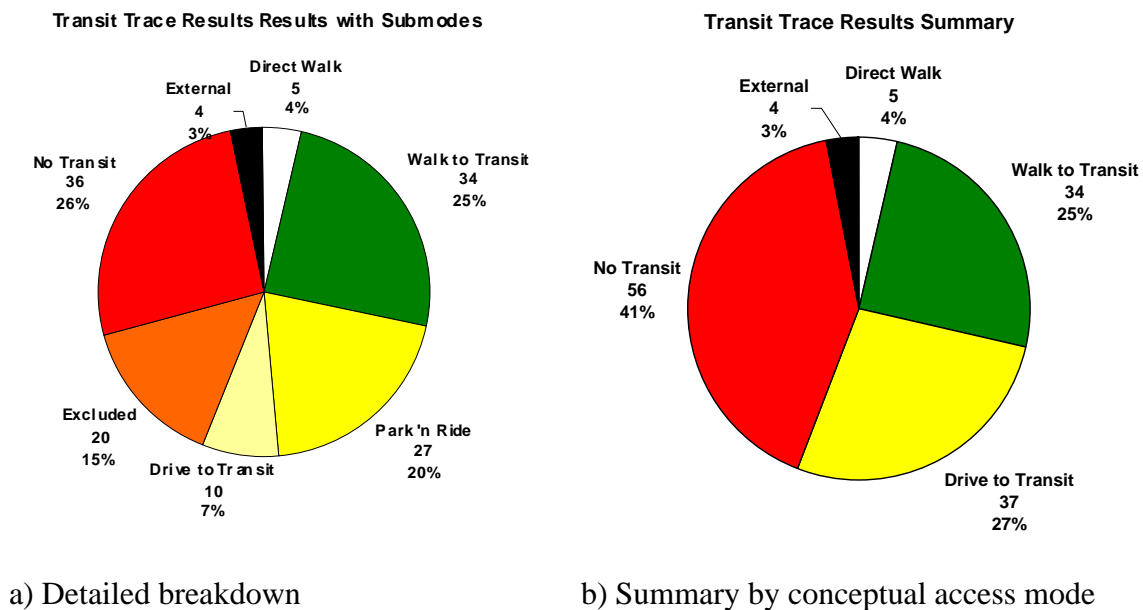


Figure 14 Transit Trace Results

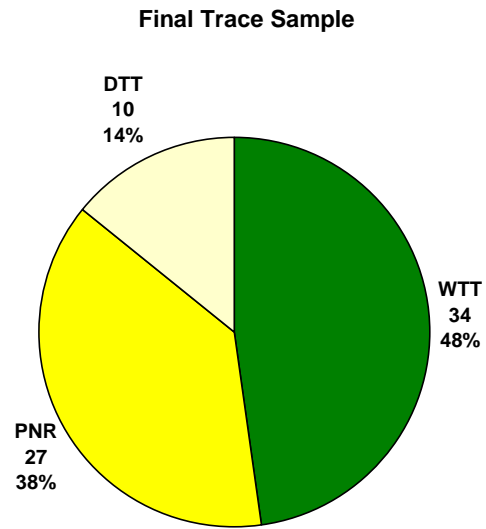


Figure 15 Final Sample Composition and Transit Trace Access Mode

## CHAPTER 7: MODEL SKIMS METHODOLOGY

The Transit Capacity and Quality of Service Manual (TCQSM) recommends utilizing regional TDM model modal skim output tables between high activity zones to obtain an indication of transit quality of service from the user perspective. Unlike the custom transit trace described earlier in the previous chapter where travel times to the network from home and from the network to the work destination are manually processed, the Skim Routine is a direct output of TDM model script.

The ARC transit skims are partitioned into three access modes: drive-to-transit, walk-to-local, or walk-to-premium. The ARC model uses these skims in the mode choice module. The single-occupancy vehicle (SOV) congested highway morning drive time skim was used for the automobile access time measure. The zonal pairs of interest to this study were extracted from the 2024 by 2024 automobile skim matrix.

A complete and usable time cost skim table for transit was not apparent in the model output. Therefore, the total transit time cost needed to be constructed from more detailed tables that listed various time components stratified by transit access mode. The time components included: walk, auto access, first wait, transfer, local in-vehicle, premium in-vehicle, and express in-vehicle. The time components were summed for each access mode using a TP+ MATRIX operation. Figure 16 presents the process flow diagram for the skim table process. The result was a set of total transit times between all zones for each transit access mode.

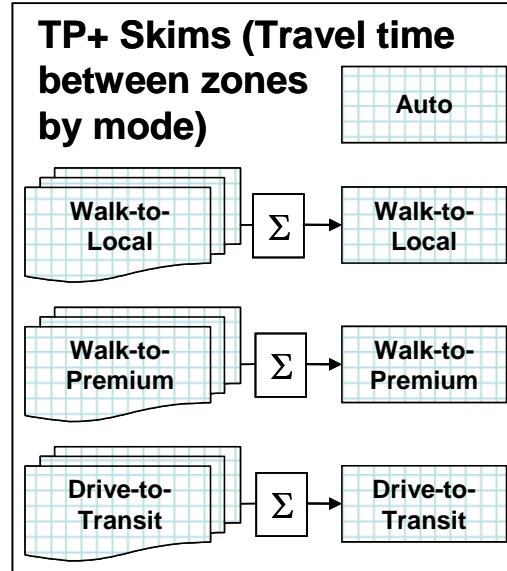


Figure 16 Skim Table Processing

Once the automobile skim and the set of three potential transit skims were calculated, the access mode that resulted in minimum total transit time was chosen for each case.<sup>15</sup> This logic mimicked the “transit user” perspective by choosing the access mode that would minimize travel time. For example, if walking to a local bus would result in a shorter total trip time than driving to a rail station, then the transit user would walk to the local bus. Selecting transit access sub-mode would minimize the difference between automobile and transit travel time, representing a best-case LOS for transit service. Acknowledging that not all trips would necessarily utilize this minimum skim, maximum skims were calculated as well. The transit access mode that maximized overall transit trip time was selected for this option. Though not a logical user choice, the maximum skim provided an upper bound on the variability of transit times produced by the model.

<sup>15</sup> For many cases, no transit skim existed because the model treated the zones as inaccessible to transit. For other cases, only one or two of the three potential transit skims were available. For example, walk-to-transit might not be possible, but the drive-to-transit could still exist. The minimum and maximum skims calculation procedure was used to resolve conflict for cases that had multiple transit skims available.

Table 4 presents example time skims (to the nearest minute) for five commute cases. The first column is the automobile travel time through the travel-demand-modeled morning congested roadway network. Automobile trip times vary from 11 to 34 minutes, depending on the case. The three transit skims are contained in the next columns. In the first case, the transit access sub-mode that would be most competitive with the 30 minute automobile trip time is drive-to-transit, which would involve a 74 minute transit trip. Walk-to-premium transit would take the longest (a 119 minute trip). The minimum and maximum sub-modes are designated in the final two columns, with the following abbreviations: Drive-to-transit (DTT), walk-to-Local (WTL), walk-to-premium (WTP), and walk-to-both (WTB). An example of the common walk-to-both is a trip originating in a zone adjacent to a rail station that is served by both heavy rail and local bus.

Table 4 Example Skim Access Mode Selection based on Total Transit Time [minutes]

Auto	Transit			Submode	
	Walk-to-Local	Walk-to-Premium	Drive-to-Transit	Minimum	Maximum
30	107	119	74	DTT	WTP
34	114	68	76	WTP	WTL
31	76	71	73	DTT	WTL
11	29	29	102	WTB	DTT
24	133	133	105	DTT	WTB

Once the skims were complete, they could be used to calculate travel time measures, which are addressed in the next chapter. Note that model skims presented above do not incorporate any time penalties for transit wait times. Hence, skim times are modeled travel times, which are lower than user-perceived times used in the mode choice modeling routines that come later in the travel demand modeling process.



## **CHAPTER 8: MEASURES**

This chapter presents the methodology used to evaluate the commuting costs of driving and taking transit by comparing a series of measures for each mode. Differences in travel times by each mode are used to calculate travel time level of service. The primary comparison was between the GPS automobile data and the modeled transit trace alternative. Secondary comparisons were made utilizing the ARC model automobile and transit skims. Transit convenience was summarized by number of transfers and perceived time indices, and automobile convenience entails trip chaining and schedule consistency. Modal monetary cost difference was also assessed.

### **Travel Time**

Difference between transit and automobile travel time is the major performance measure of transit service from the passenger point of view. The total automobile trip duration was obtained for each trip within the month (less any chained stop time, see Chapter 10 Trip Chaining and Convenience Measures). The automobile trip time impedance was determined by the median trip duration for all unchained trips along a driver's primary commute route. The sum of all transit trip components including access, wait, travel, and transfer comprised the total transit time. Once the automobile and transit travel times were assembled, the TCQSM transit-automobile travel time LOS was applied.

## **Convenience**

### Automobile Trip Chaining

Trip chaining occurs when, for example, a commuter does not simply go directly from home to work but stops at a convenience store or a fast food drive-thru. The automobile provides a level of flexibility to undertake such activities that fixed-route transit is unlikely to match. Evaluating the prevalence of trip chaining behavior of automobile commuters is an important element of determining transit mode choice feasibility.

As mentioned in Chapter 5 (Automobile Trip and Sample Selection) the number of chained trips, number of chain segments, and duration of chain stays were obtained from the GPS data. Trip chaining was identified by vehicles leaving the roadway network for a certain time threshold (see Li, 2004). The types of trip chains could also be differentiated. “Stops” were associated with engine-off/engine-on events, where the vehicle was actually stopped and off while the individual participated in the chained activity, for example stopping in at the convenience store. “Drops,” on the other hand, maintained engine-on status, examples of which would be a drive-thru or child drop-off at school. The number of trips in the month for each case containing at least one stop and the number containing at least one drop were tallied (the number of stops or drops within each trip was not retained). Commute routes could be identified from the GPS data, as well (see Li, 2004).

This measure of utility or convenience was obtained by finding all non-chained trips along the primary route. The number of these “direct” trips was divided by the total

monthly number of trips for each case to obtain a percent direct primary metric, which represents inverse trip chaining. A commuter who chains most of their monthly commute trips might derive a high level of utility that would need to be foregone if mode switch were to occur.

#### Automobile Schedule Consistency

Another related advantage of automobile travel over transit is the flexibility to come and go as one pleases. The flexibility provided by the automobile can be reflected in the consistency of commute trip home departure and work arrival times. The consistency was measured by the percentage of each driver's monthly commute trips that fell within plus or minus five minutes of the median time. This metric was applied to both home departure and work arrival times. The home departure time is more relevant to individual time schedules, while the work arrival time also provides an indirect measure of travel time variation and/or congestion effects.

Particularly with reference to departure time, if a commuter already maintains a consistent schedule for the driving mode, then the burden of conforming to a fixed transit schedule would be minimal. Conversely, individuals with highly variable work commute trip departure time can be said to derive much utility from such flexibility that would be sacrificed as a result of mode switch. The ten minute window (plus or minus five minutes) was selected over other time periods to produce the most nearly normal distribution with an approximate mean of 50%<sup>16</sup>.

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<sup>16</sup> The goal was to create a variable that could be used to differentiate the various cases as much as possible. Had a larger time window been selected, more schedule consistency would have been indicated, but the

### Transit Transfers

The total number of real transit mode to transit mode transfers was summed for each transit case. The results of the transit trace often produced excessive successive transfer and/or walking segments. Future work could impose restrictions on the mode transfer sequence allowed, for example disallowing walk-to-walk and transfer-to-transfer. Cases of successive multiple walk segments were aggregated into a single walk segment in the data processing to ensure proper tallying. The transfers were manually counted between real transit modes instead of using the sum of the transfer segments traversed.

### Perceived Transit Time

TP+ utilized the mode factors, transfer wait factors, and transfer penalties to weight the “actual” modeled time of various trip segments according to theoretical value of time. The traces were built based on shortest perceived time cost paths. Though this study’s travel time analysis uses unweighted time, the weighted perceived time for each transit trace was retained for comparison. The concept of value of time addressed by these various mode factors and perceived time provides a measure of utility or inconvenience. See Chapters 2 (Background) and Chapter 3 (Atlanta Context) for a detailed discussion of perceived time and factors used in the ARC model, which were employed in the transit traces.

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data would have bunched on the upper end of the spectrum. In addition, a five-minute departure window is reasonable relative to the scale of schedule adjustment required to conform to transit.

### Monetary Cost

Generally, a major part of the choice set is monetary cost. However, due to minimal employee parking costs<sup>17</sup>, lack of automobile tolling, and unpronounced pricing variability in transit in Atlanta, monetary cost is not of paramount importance in evaluating the commute mode choice set for Atlanta. Nevertheless, the modal costs were compared for each commute.

Given the flat fares (in time and distance) and free transfers characteristic of current transit in Atlanta, the first transit mode determines transit out-of-pocket cost. The respective transit fare can then be applied according to Table 5. The sample contained only once case of reverse commute. GRTA Xpress bus was the first transit mode, and the commute classification was radial outbound. One-way, full-fare costs were assumed and applied to all other cases. MARTA provides free daily parking for commuters driving to transit, and free parking is also provided at express bus PNR parking lots.

Table 5 Transit Fares

Operator	Service	Mode	ARC Fare	Fare
MARTA	Local Bus	14	\$ 1.75	\$ 1.75
	Heavy Rail	15	\$ 1.75	\$ 1.75
	Express Bus	16	\$ 1.75	\$ 1.75
CCT	Local Bus	24	\$ 1.75	\$ 1.25
	Express Bus	26	\$ 1.75	\$ 3.00
CTran	Local Bus	34	\$ 1.75	\$ 1.50
	Express	36	\$ 1.75	\$ 1.50
Gwinnett	Local Bus	44	\$ 1.75	\$ 1.75
	Express	46	\$ 2.00	\$ 3.00
State	Local Bus	54	\$ 1.75	\$ 3.00
	Express Bus	56	\$ 1.75	\$ 3.00
		(reverse commute)		\$ 1.50

<sup>17</sup> The Atlanta Employer Commute Options Survey, a component of the Commute Atlanta project, found the majority of Atlanta-area employers provided free parking to employees. See (Zuehlke and Guensler 2007) for a discussion on employer perception and implementation of commute alternative strategies.

Data from the American Automobile Association (AAA) data were used to estimate the total and operating costs associated with each driver's automobile commute (see Figure 7). The AAA's 2007 estimates of automobile costs include fuel, maintenance, insurance, financing, depreciation, and governmental fees (AAA 2007). The calculations assume an annual mileage accrual of 15,000 miles. The small, medium, and large sedan rates were averaged to represent the "Auto" classification in the Commute Atlanta dataset. This yielded total cost of about 52, 58, and 67 cents per mile for automobiles, vans, and sport utility vehicles/light-duty trucks (SUV). Considering only operating costs, costs for automobiles were 15, vans were 16, and SUVs were 19 cents per mile.

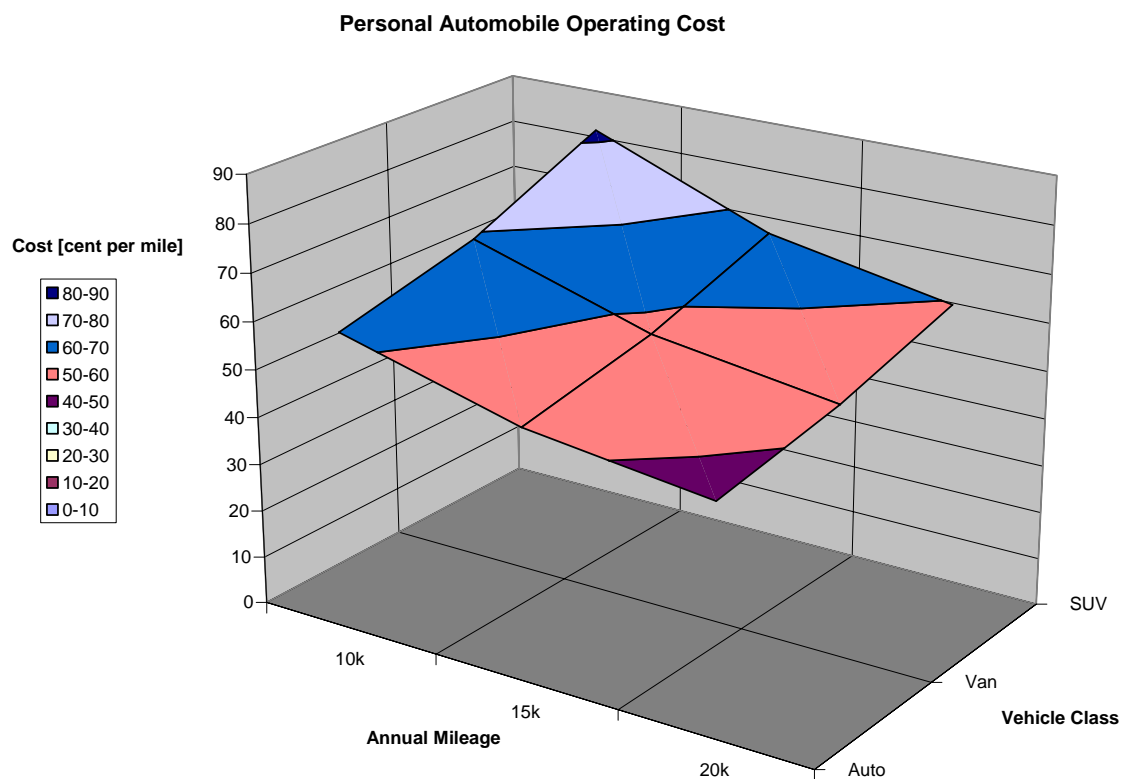


Figure 17 Automobile Costs

## **CHAPTER 9: TRAVEL TIME COMPARISON**

### **Work Commute Automobile Alternative**

The median commute travel time of each person's commutes throughout the month is used as the measure of automobile travel time. The travel times were obtained by subtracting any trip chain-related stopped time from the commute duration (Li 2004). Trip travel times range from just below 10 minutes to about 85 minutes and from a third of a mile to 38 miles, with an average driver taking about 37 minutes to commute 17 miles. On average, the monitored commuters made about 15 morning work commute trips a month, with a range from the minimum of 10 to a maximum observed 21. The average driver uses two major routes, though up to five routes were observed for a single driver. On average over 55% of the trips are along the primary route without trip chaining, though approximately 18% of the monthly commutes involved at least one drop-off (engine-on) and 22% involving at least one stop (engine-off). On average, a driver departs (arrives) within plus or minus five minutes of the median departure (arrival) time for approximately 40% of that driver's monthly commutes.

### **Commute to Work Transit Alternative**

Transit travel times based upon transit trace paths range from about 40 minutes to about 200 minutes. On average, transit commutes take would about an hour and fifty minutes. On average, commuters using each mode spend a total of 22 minutes on local, 30 minutes on express, and 12 minutes on rail per commute. The average drive-to-transit time would be 18 minutes, and walking time would average 12 minutes for commuters using transit

(including both the walk from origin to transit and from transit to destination). An average of two minutes would be spent transferring per trip, and the number of transfers per trip would range from zero to five.

### **Travel Times by Various Methods**

Figure 18 presents the average travel times and 95% confidence intervals on the travel times by each mode and data source. The automobile times were obtained from both the Commute Atlanta GPS data and from the ARC model skim. The transit time was obtained from the ARC model transit skim and the customized TP+ transit trace. The perceived time accounts for value of time of each transit trip component included in the four-step model<sup>18</sup> and was used by TP+ in shortest path building. The total trace time is un-factored is used in LOS analysis below.

The automobile is faster than transit, both according to the skims and according to the revealed preference drive data and the modeled transit alternative. The automobile trip times revealed by GPS are 45% shorter than the model-reported skims. The difference is significant at the 95% significance level, indicating the actual sample commutes in 2004 might not experience as much travel delay as the modeled congestion might indicate. Further, the transit trace times were longer than the minimum transit skims by about 24% and were statistically significant at the 95% significance level. The maximum transit

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<sup>18</sup> In the ARC four-step travel demand model, transit wait time is weighted as being 1.75 (for premium) or 2.5 (for non premium transit) times more important in transit decision making than is time en-route. Hence, the transit trace perceived values are calculated by multiplying transit wait times by a factor of 1.75 or 2.5 and adding this time value to the on-transit and transfer time values to reflect the perceived time that transit users are likely to assign to the transit mode. See Chapter 2 (Background) for more information.



skims more closely resembled the transit traces. Depending on the specific access modes selected, the ARC model might under represent the difficult of the transit mode.

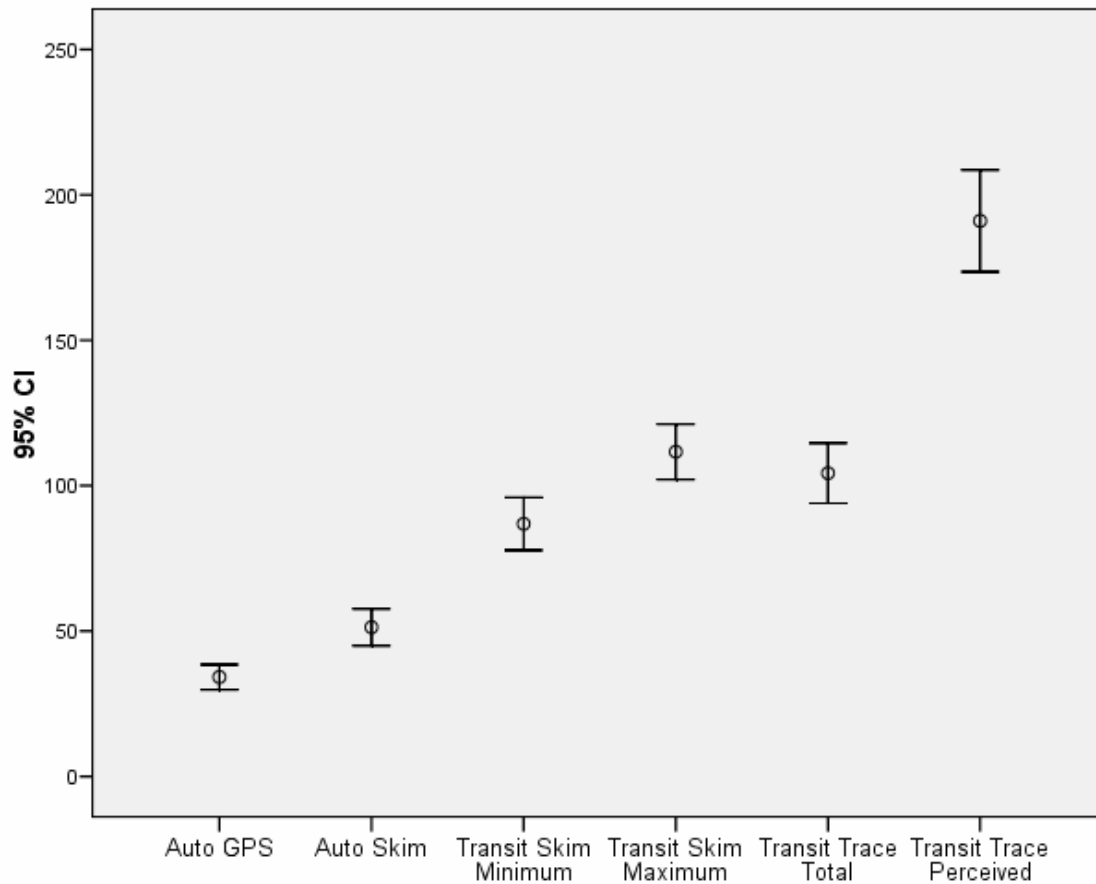


Figure 18 Travel Times by Mode and Method

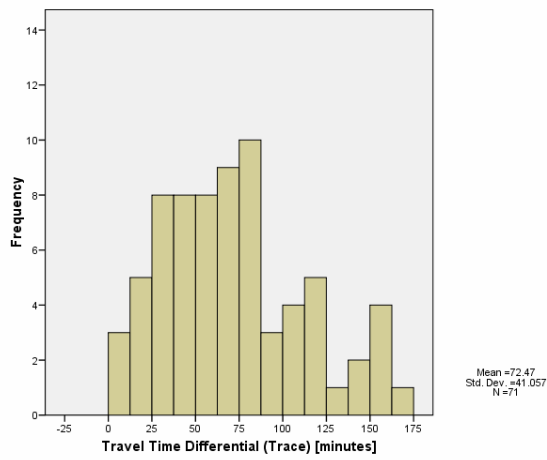
### Transit vs. Automobile Travel Time Level of Service

Based on the revealed preference automobile commute data and modeled, manually screened transit paths, commute travel times by transit greatly exceed that of automobile. Using the difference in travel time between transit and automobile and applying the associated Level of Service value indicates that the average difference in travel time is 72

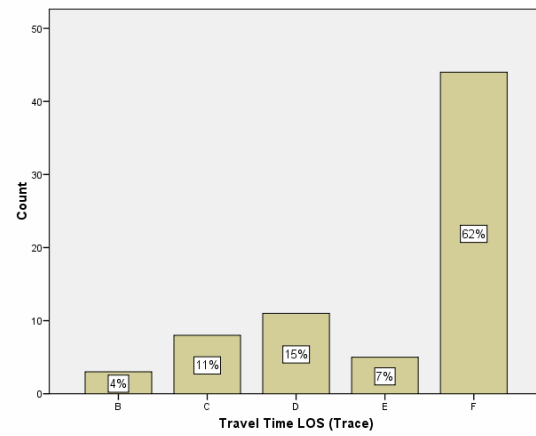
minutes, and the vast majority of commutes in the sample experience a LOS F (see Figure 19).

As discussed earlier, standard automobile and transit skim tables were output from the travel demand model. Zone-to-zone travel times relevant to the sample cases were extracted from the automobile and transit skim tables output from the travel demand model. Figure 20 shows the difference in travel time and travel time LOS by the minimum skim, and Figure 21 gives the same data for the maximum skim. Figure 22 provides the counts for the relative numbers of transit access modes selected under the minimum and maximum scenarios. Using the minimum skim, the preferred transit access mode for the vast majority of the zone pairs that had transit skims was drive-to-transit (see Figure 22a). In contrast, walk-to-local often was often the worst-case, maximum skim.

The difference between preferred and worst transit access mode are very large, and the variability in transit time by transit access mode is also large. The model skim tables show slower auto times and faster transit times than results obtained by individualized transit trace and automobile GPS data. This would cause this method to underestimate the quality of service. That is, using TDM model skim tables, as suggested in the literature (Perk and Foreman 2003), would likely result a more favorable interpretation of transit quality of service than that experienced by the user. If the transit access mode choice is based on minimum total transit time transit mode choice, the ARC model may under-represent the difficulty of taking transit.



a) Travel time difference



b) Travel Time LOS

Figure 19 Transit-Automobile Difference in Travel Times and LOS by Trace

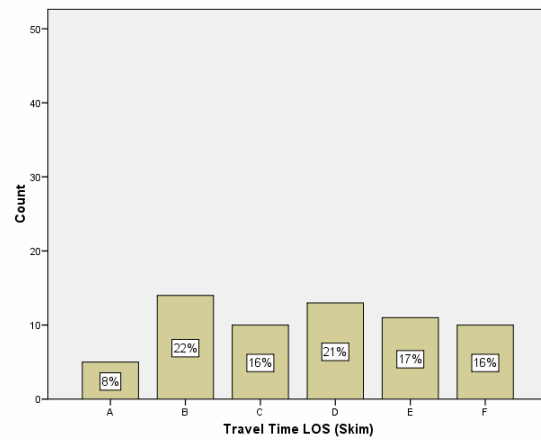
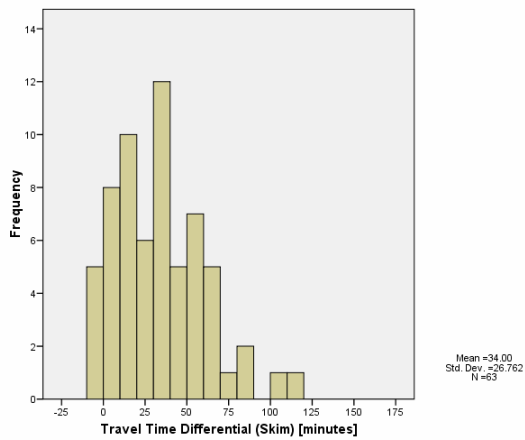


Figure 20 Figure Transit-Automobile Difference in Travel Times and LOS by Skim

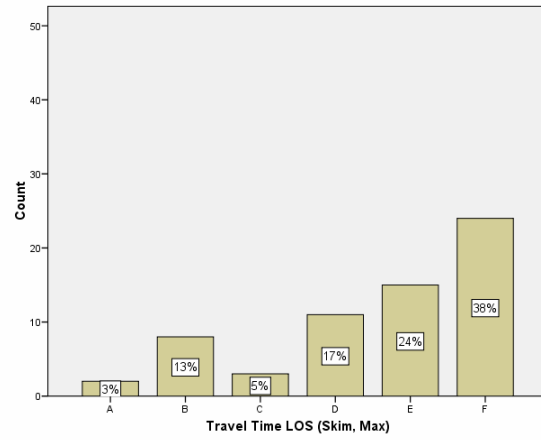
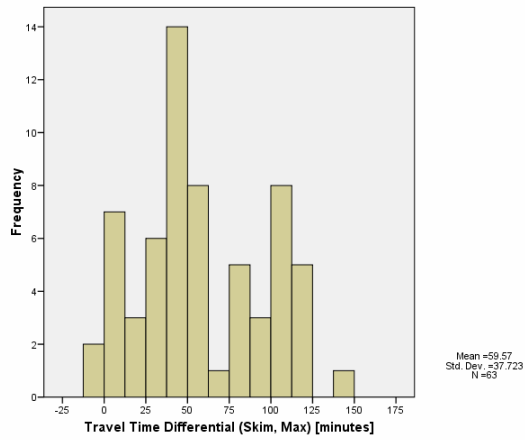
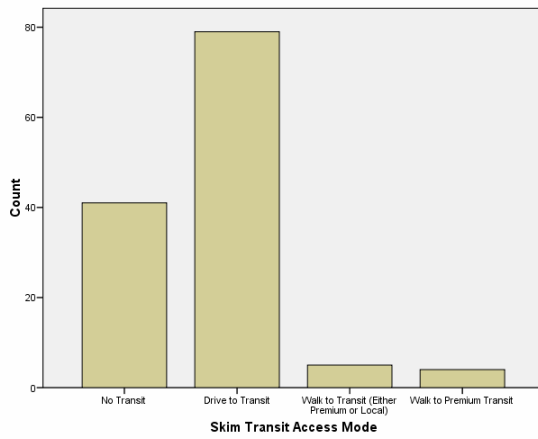
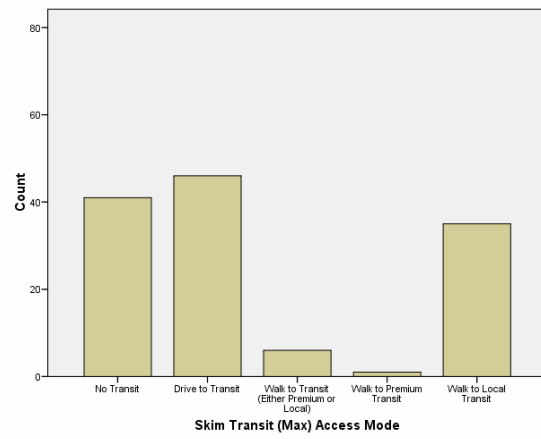


Figure 21 Transit-Automobile Difference in Travel Times and LOS by Skim with Maximum Access Mode



a) Minimum Skim Access Mode



b) Maximum Skim Access Mode

Figure 22 Transit Skim Access Mode by Minimum and Maximum

## **Comparison of Transit Traces and Skims**

Even though the walk support links tend to under-represent the walk distance from the zone (see Chapter 6 Transit Traces Methodology), rarely is walk to transit the quickest transit skim access mode, as was seen in Figure 22.<sup>19</sup> That is, for the majority of cases, the transit skims yielded a shorter drive to transit than walk to transit time, even for those cases deemed suitable for walk access in this study by transit trace (see Figure 23).

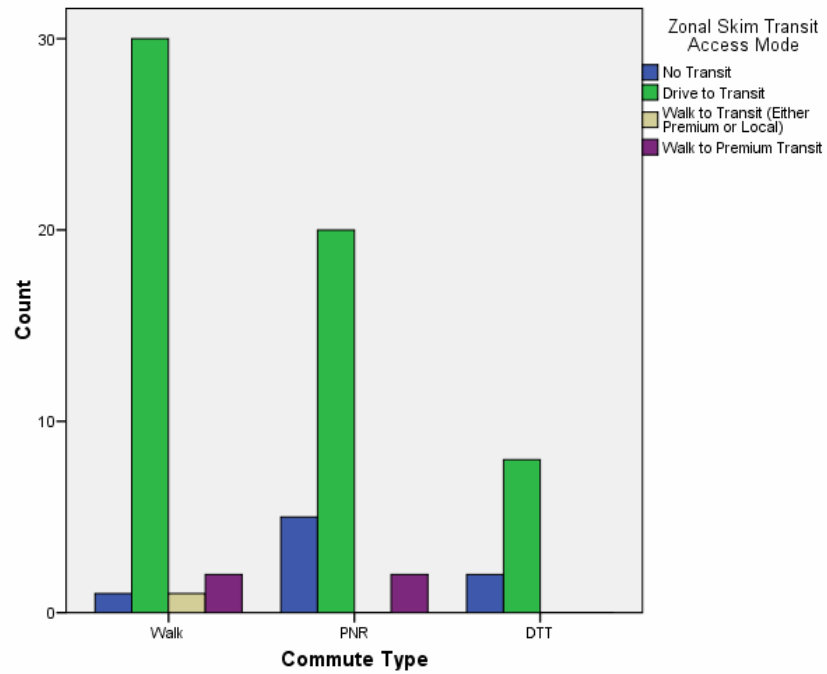
Though perhaps not directly problematic for the mode choice model working at the regional level, this finding identifies a potential inconsistency in the relative attractiveness of the transit access modes. Even for walkable zones, the drive-to-transit time is shorter than the walk-to-transit time, according to the transit skims. This might be more reasonable for the average trip from the zone, but it is not consistent with the individual cases of this study. Additional research in this area is warranted.

### Implications of Model Skims in the Four-Step Model

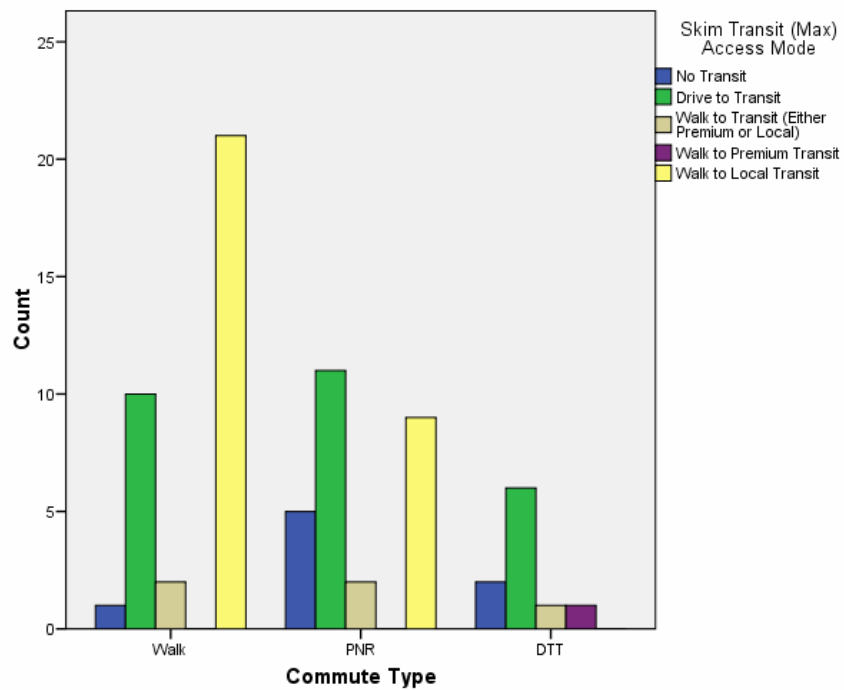
As indicated in Figure 23, the model skim tables provide slower auto travel times and faster transit travel times (assuming minimum cost transit access mode selection) from zone to zone than did the results obtained by individualized transit trace and automobile GPS data. This could result in erroneous estimations of automobile and transit quality of service. That is, using TDM model skim tables, as suggested by the TCQSM, would likely result a more favorable interpretation of transit quality of service than that experienced by the user. Similarly, use of modeled auto skims may result a less favorable interpretation of automobile quality of service than that experienced by the user.

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<sup>19</sup> In fact, walk-to-local is much more likely to be used in the maximum skim than the minimum skim.



a) Minimum Skim Transit Access Mode by Trace Commute Type



b) Maximum Skim Transit Access Mode by Trace Commute Type

Figure 23 Skim Access Mode by Trace Access Mode

## **CHAPTER 10: TRIP CHAINING AND CONVENIENCE MEASURES**

The comparative analyses presented in the last chapter indicated that the automobile was the preferred alternative for most of the commuters represented in this study, and the transit travel time differences and the variability in travel time differences were large. This chapter assesses the implications of the large amount of trip chaining that is occurring in the commute travel for these households. The convenience measures analyzed are automobile (1) trip chaining and (2) schedule consistency and transit trip (3) transfers and (4) time perception.

The automobile direct trip percentage is the primary trip chaining metric and indicates the portion of each participant's monthly work commute trips that occur along the primary route without trip chaining (no stops or drop-offs). However, several cases did not have direct commutes because trip chaining occurred on every single journey to work. These cases needed to be treated separately to identify their dominant commute behavior.

### **Case Study: Main Chained Commutes**

Eleven drivers did not have any direct trips along their primary routes. That is, eleven commuters had chained trips for every single commute to work, which contained at least one drop-off or one stop. These cases required more complex treatment to determine the temporal automobile impedance than simply using the trip duration. Although there was no "direct primary route," a "main" commute could be identified, which corresponded to the most prevalent trip type for each driver. For most of the 11 cases, the drivers utilized

their primary route and either stopped or dropped-off on every single trip in the month. The travel time of each of these “main” trips was calculated by subtracting the time spent stopped or dropping-off from the trip duration. Thus, time participating in these stop and drop-off activities was not counted within the commute trip impedance. The median main trip travel time was obtained for each commuter to represent the temporal automobile impedance.

Table 6 summarizes these commutes. The number of main trips was divided by the total number of home-to-work commute trips for each driver to produce the percent main metric. Most drivers stopped along their primary route, although four engaged in trip chaining activity along their primary route that did not involve turning off the engine.

In addition to providing a basis for characterizing the home-to-work commute, the Commute Atlanta data enable detailed understanding of the variability in personal automobile travel behavior. Travel times exhibited greater variability than distance due to the high level of refinement of the route detection algorithms (Li 2004). Given the relative stability of distance, the average distance of all a commuter’s main trips was used to represent that case’s aggregate distance impedance.

The time-distance profiles of the main trips are presented in Figure 24. Note the stability in commute distance is apparent in the flatness of each case’s profile. The scatter along the time dimension indicates the day-to-day variability in travel times for the same route. The interquartile range of travel time is one way to account for the variability (see Table



6). A noteworthy comparison can be made from box 2394, for which two trip types tied for the “main” trip type, with seven instances each. All 14 trips involved stop chains, but seven were along the primary and seven were along a secondary route. The distance of the primary route is slightly less than the distance of the secondary route, and trip distances along each route are quite self-consistent. The travel times are more dispersed, though they fall within the same approximate range for both routes.

Table 6 Main Trips

	Trips					Distance	Time (travel)	
	Main	Total				[miles]	[minutes]	[minutes]
						Mean	Median	Interquartile
Box	n_main	n_tot	%	Route	Type	d_mean	t_tt_med	Range
1017	14	15	93%	1	Stop	30.04	44.75	15.01
2011	15	15	100%	1	Stop	10.01	25.82	4.90
2020	9	14	64%	1	Drop	20.21	50.97	11.75
2077	18	19	95%	1	Stop	19.98	57.81	10.92
2205	14	18	78%	1	Drop	23.24	43.97	9.41
2218	14	19	74%	1	Drop	29.20	85.28	5.04
2243	16	19	84%	1	Stop	36.28	81.06	21.58
2303	10	16	63%	1	Drop	22.33	32.82	2.97
2385	18	18	100%	1	Stop	30.34	43.29	4.91
2444	9	11	82%	1	Stop	5.90	30.35	7.53
2394	7	16	44%	1	Stop	32.83	79.90	13.53
2394	7	16	44%	2	Stop	36.48	80.63	9.93

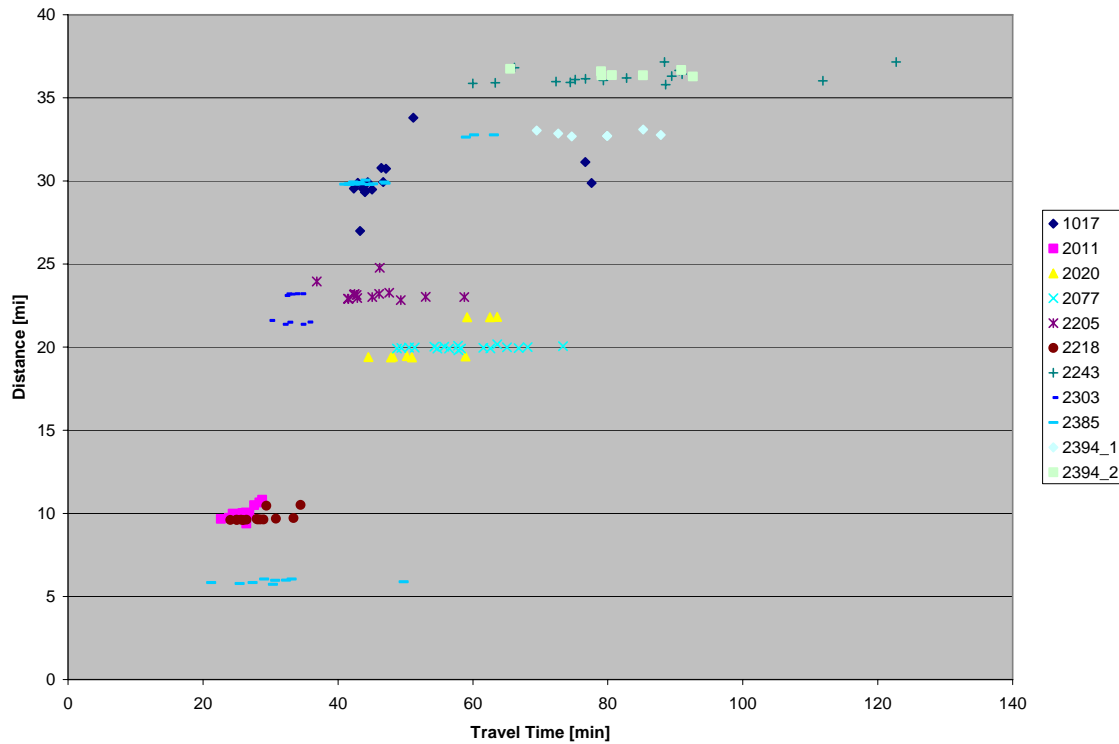


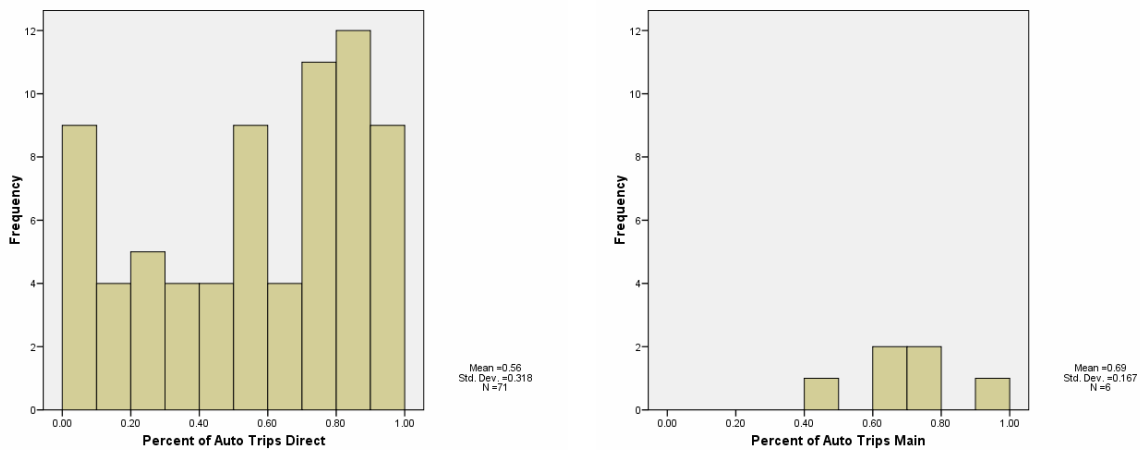
Figure 24 Distance and Time Sensitivities

## Measures of Convenience

### Automobile Trips

Once the main trips were incorporated into the dataset, the analysis of trip chaining could proceed. The impact of trip chaining for these cases was obtained by the percent direct trips metric; the percentage of all commute trips that were along the primary route and were direct. A low percentage of direct commutes indicates a high level of trip chaining. Commuters are unlikely to easily forgo the utility derived from such automobile-induced flexibility. Conversely, commuters who are already just going straight to work would not be missing much if they were to switch to transit.

Figure 25a presents the percentage of automobile trips that were direct along the primary route. Figure 25b charts the percentage of automobile trips that were classified as main. Though all of the main trips would be grouped at zero if they were included in Figure 25a, Figure 25b provides further insight into the variability of commute travel. Most drivers do not drive to work the same way every day. For example, only 9 of 71 (12.7%) drivers commuted directly to work along their primary path more than 95% of the time. This lack of consistency is due in large part to trip chaining<sup>20</sup>.



a) Direct trips

b) Main trips

Figure 25 Convenience – Automobile Trip Chaining

As for schedule consistency, the percentages of each participant's monthly commute trips that departed (arrived) within a ten-minute window of the participant's median departure (arrival) time were calculated. Commuters with a large percentage of trips occurring within the specified time windows would depart from home and arrive at work nearly the same time every day. The implication is that this type of commuter would already

<sup>20</sup> Another factor is number of commute routes, which was retained in the dataset and could be controlled.

exhibit the consistency of schedule that would be required to conform to a transit timetable. The converse applies to commuters with a low schedule time consistency who might find sticking with a set schedule to be a major barrier to taking transit. This assumes transit headways on the order of current conditions in Atlanta: between five and 10 minutes for heavy rail and perhaps half hour local bus service. Were transit service to improve to very frequent headways, the schedule consistency factor would become moot. However, that prospect is quite far removed. Schedule consistency behavior is also closely related to trip chaining, which might require deviation from any set schedule.

The schedule consistency of Commute Atlanta participants was quite varied across the sample (see Figure 26). Only 4 of 71 (5.6%) drivers departed home within five minutes of their typical (median) departure time more than 95% of the time. Note the very similar consistency for both the home departure and work arrival. This would indicate congestion effects might not significantly influence the variability in time of arrival at work for the sample.

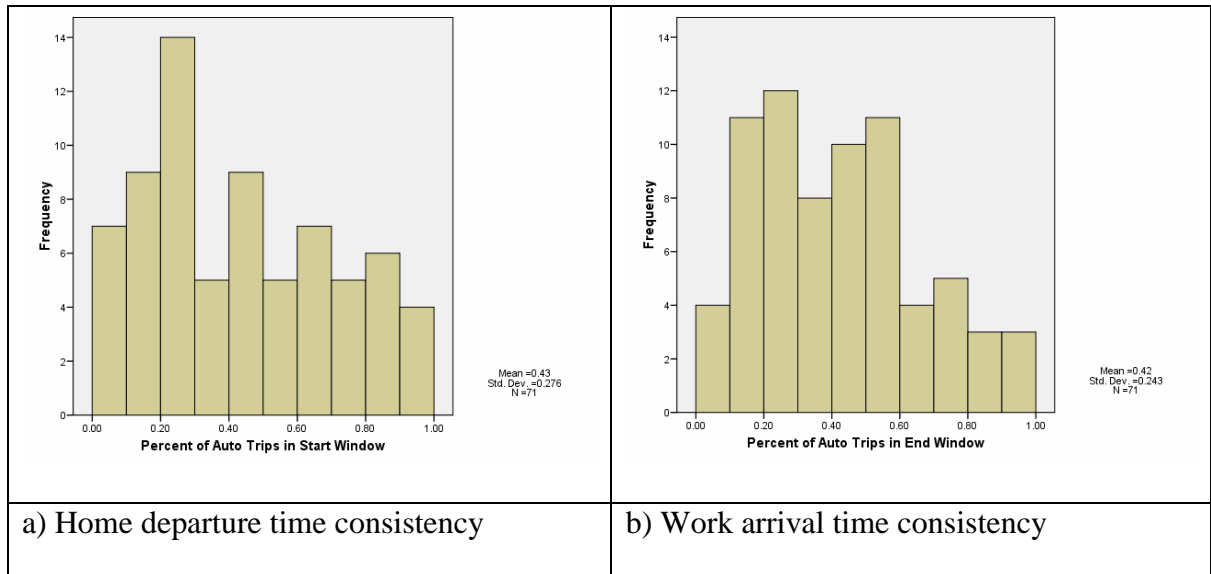


Figure 26 Convenience – Automobile Schedule Consistency

### Transit Trips

Transit analogues to the automobile convenience measures of trip chaining and schedule time are transfers and perception of time. Transit trips most commonly required two transfers (see Figure 27). More than half of the commute cases required either one or no transfers. Larger numbers of transfers were rare, with the most arduous trip requiring five transfers. About three quarters (52 / 71) of the transit traces required at least one transfer.

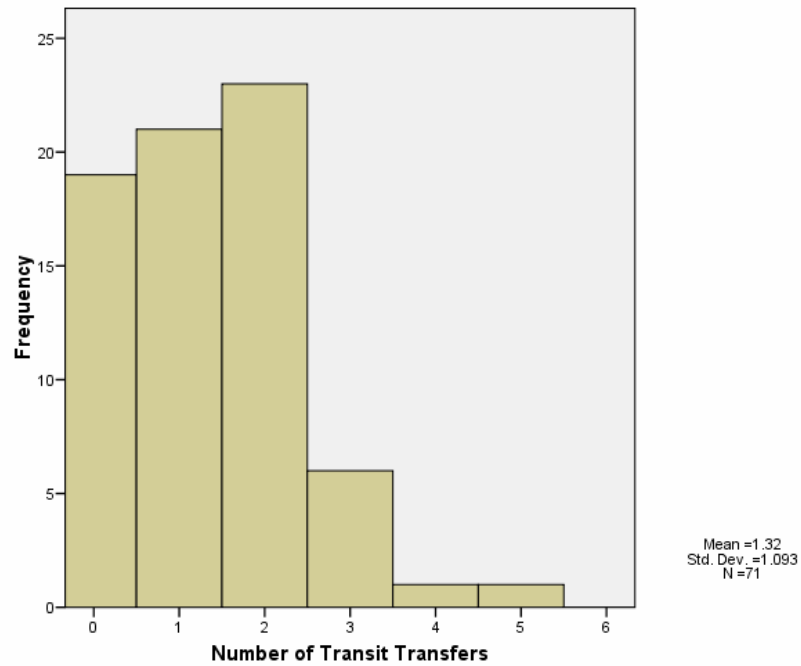
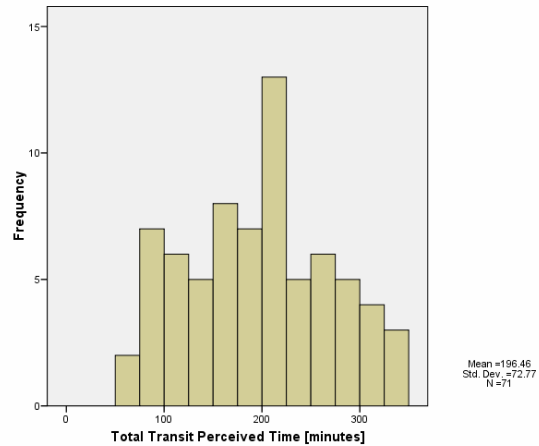
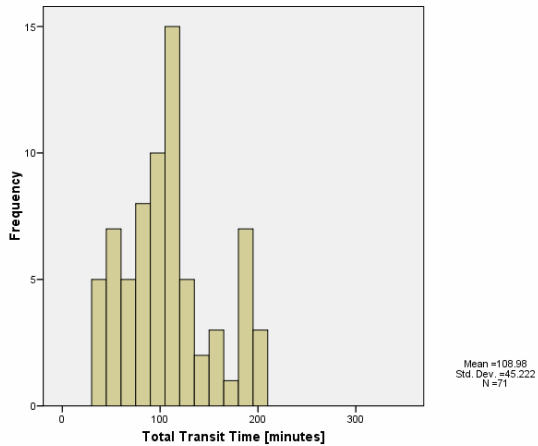


Figure 27 Transit Transfer Distribution

Mode factors and waiting penalties caused the perceived time to exceed “actual” modeled total transit time significantly (see Figure 28). The average perceived time was just under 200 minutes compared to about 110 for the un-factored time. Using these averages, an approximate, total trip mode factor would be about 1.8. Based on pair-wise analysis, mode factors for transit commutes in the sample ranged from 1.25 to 2.5 (see Chapter 12 Composite Transit Attractiveness Score).



a) Un-factored transit time

b) Perceived transit time

Figure 28 Convenience – Transit Perceived Time

Observing variability in travel behavior enabled by the flexibility of the automobile, considering the numbers of transfers required to complete transit commutes, and applying the ARC model assumptions about rider perception of time, the automobile appears to be much more convenience than transit.

In addition to the immense travel time burden and convenience deficiency of transit relative to the automobile, monetary cost consideration will help shape the modal comparison.

## CHAPTER 11: MONETARY COST COMPARISON

The relative monetary costs for each case were examined based on transit fares, AAA automobile costs, and automobile mileage. Transit systems in Atlanta charge flat fares in both distance and time. In addition, transfers are free, with fare charged to the transit system of first access. The distribution of the first transit mode of each commute trace is reported in Figure 29. Half of the transit trips traced started on MARTA, the majority of which were local bus. The next major mode share is express bus, split evenly between GRTA and CCT. Suburban local buses (CCT and GCT) were utilized less.

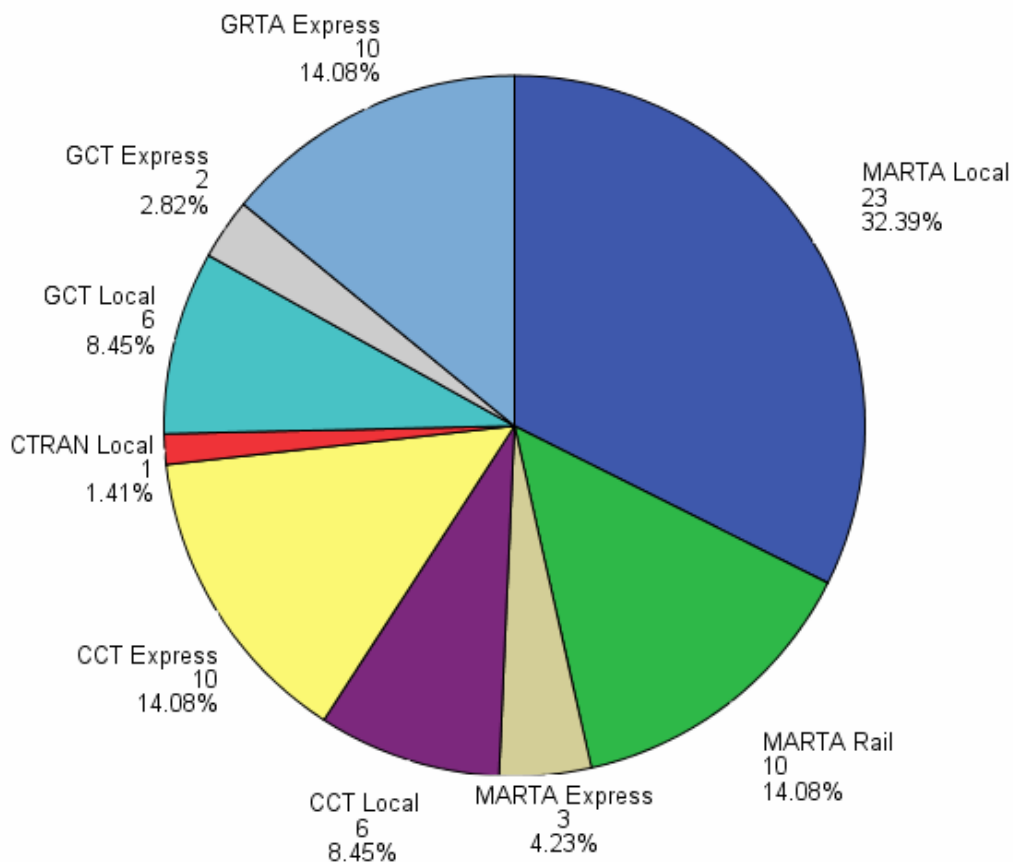
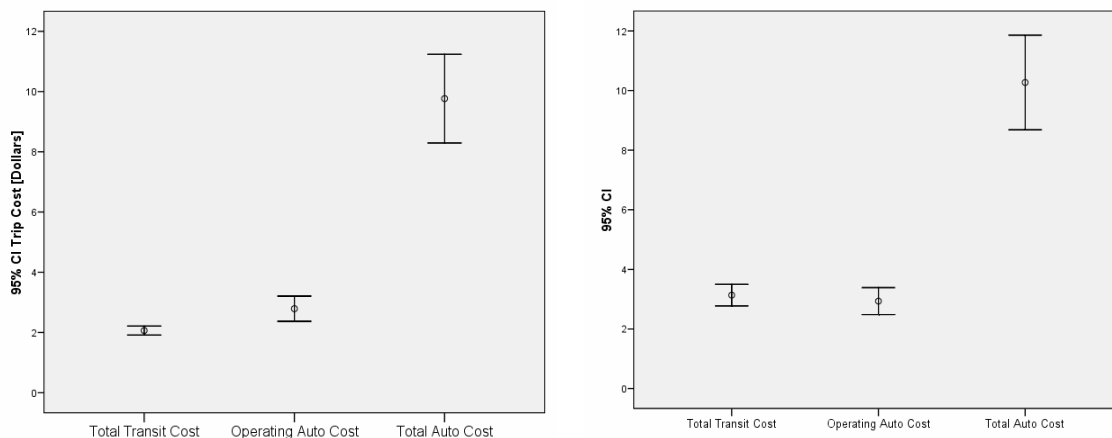


Figure 29 Distribution of First Transit Mode Based Upon Transit Trace Paths



Figure 30 indicates that not considering DTT automobile costs within transit costs, taking transit is cheaper than operating an automobile. However, once the drive access costs are included, the distinction between transit and automobile operating costs is eliminated. Nevertheless, when total automobile costs are considered, the costs of driving (about 10 dollars per one-way commute to work) vastly exceed the costs of transit (about three dollars).

A more detailed analysis is presented in Figure 31 , which utilizes cost differentials and cost ratios between the transit and automobile costs, considering both operating and total automobile costs. Naturally, the breakeven point between transit and automobile costs on the differential charts is the zero point. Figure 31a illustrates about half of the cases with cheaper transit and about half with cheaper automobile. Automobile costs greatly outweigh transit costs for the majority of cases when total automobile cost is considered (see Figure 31b). A similar shift occurs between the operating and total automobile costs for the cost ratio, centered on one (see Figure 31 c and 31d).



a) Fare-only transit cost

b) DTT costs included in transit

Figure 30 Monetary Costs

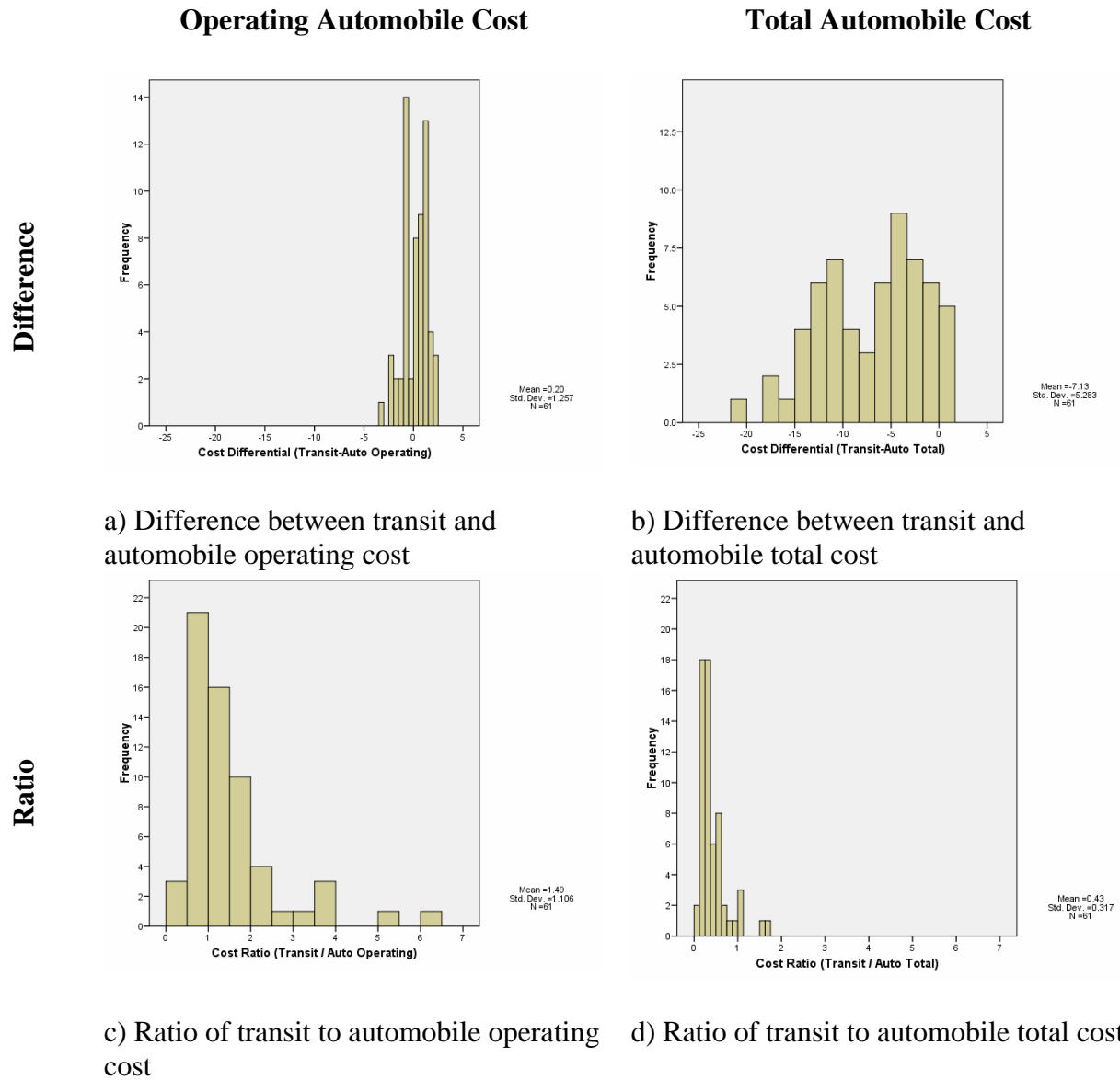
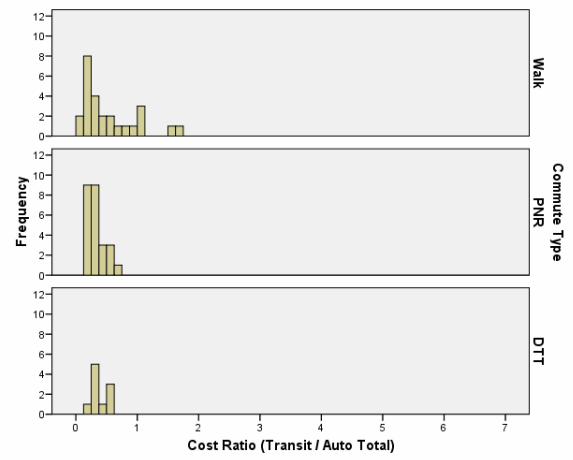
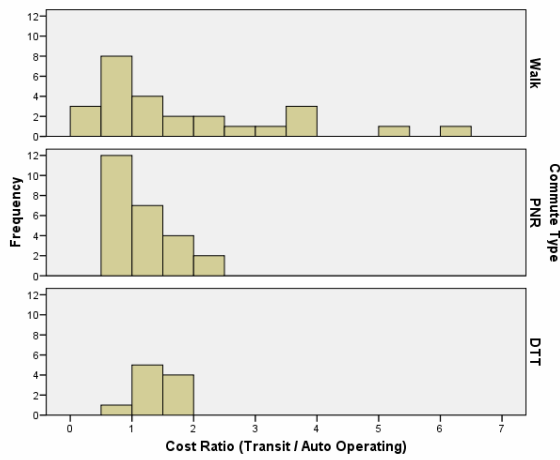


Figure 31 Detailed Cost Comparison between Transit and Automobile

Figure 32 compares the modal cost using the cost ratio across the three commute types.

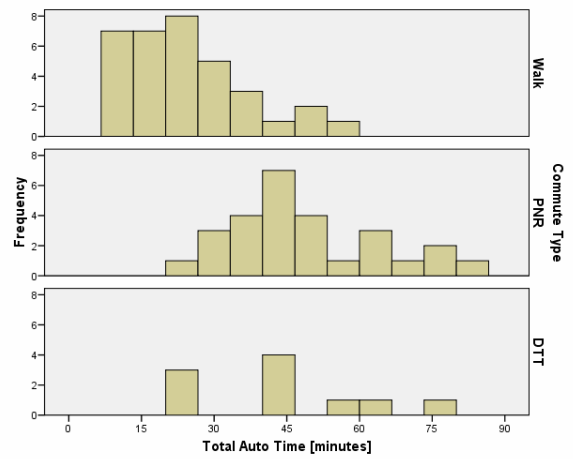
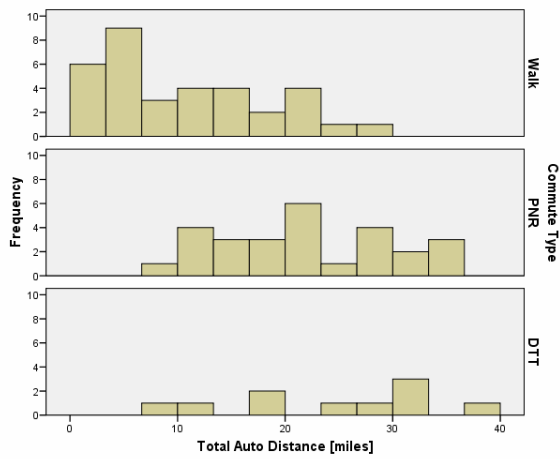
Transit is more expensive than driving for a surprising number of the cases in the WTT set, given the moderate transit fares and free walk access. However, Figure 33 reveals the WTT cases tend to be associated with shorter (distance and time) automobile trips than PNR or DTT.



a) Operating cost ratio

b) Total cost ratio

Figure 32 Cost Comparison by Commute Type



a) Distance

b) Time

Figure 33 Distance and Time Distributions by Commute Type

## CHAPTER 12: COMPOSITE TRANSIT ATTRACTIVENESS SCORE

As an example of developing a composite score of transit attractiveness, the measures of the various components were normalized to a scale from zero to one. In this effort to characterize case profiles, the Commute Atlanta trip data and transit traces were used. Table 7 summarizes the types of indicators used for each category and the variables involved in the calculation. Scaling each measure to the common spectrum enabled a composite score to be summed (see Table 8).<sup>21</sup>

Table 7 Composite Transit Attractiveness Indicator Components

Category	Type	Variable 1	Variable 2
Travel Time	LOS	Transit travel time	Automobile travel time
Cost	Ratio	Total transit cost	Automobile operating cost
Transfers	Count	Number of transfers	N/A
Perception of Time	Ratio	Total transit time	Total perceived transit time
Trip Chaining	Ratio	Trips along primary route and unchained	Total monthly commutes
Schedule Consistency	Ratio	Trips started within +/- 5 min. of median	Total monthly commutes

Table 8 Composite Transit Attractiveness Scale Spectrum

F	E	D	C	B	A
0	0.2	0.4	0.6	0.8	1
<b>Travel Time</b>					
> 1 hr slower		... ..			Transit faster
<b>Monetary Cost</b>					
> 4x cost		... ..			Transit cheaper
<b>Number of Transfers</b>					
Many transfers		... ..			Few transfers
<b>Perception of Time</b>					
Perceived > actual time		... ..			Perceived = actual time
<b>Direct Commutes</b>					
Many trip chains		... ..			Goes directly to work
<b>Schedule Consistency</b>					
Inconsistent		... ..			Consistent

<sup>21</sup> As analysis of sensitivity to various weighting schemes and identification of principal components are beyond the scope of this study, the weight of each measure was assumed to be one.

The TCQSM travel time level of service was used to represent the travel time competitiveness of transit relative to automobile. LOS A corresponds with faster transit than automobile travel times. Each successive LOS from B to E indicates successive deterioration in transit travel times relative to automobile, and LOS F is associated with transit trips requiring more than one hour more than automobile.

The monetary cost indicator compared automobile operating costs with total transit cost (including DTT automobile costs) because operating costs are more likely to resemble out-of-pocket realistically considered in the individual trip decision<sup>22</sup>. The highest LOS are assigned to trips that are cheaper by transit than by driving, and the rating decreases as transit becomes less competitive with automobile (see Table ).

Table 9 Cost Scale and Example LOS

Scale	LOS	Cost Ratio	Meaning
1.0	A	0.0-0.5	Transit is much cheaper than and up to half the cost of auto
0.8	B	0.5-1.0	Transit is between half and the same cost as auto
0.6	C	1.0-1.5	Transit is up to 1.5 times as expensive as auto
0.4	D	1.5-2.0	Transit is between 1.5 and two times as expensive as auto
0.2	E	2.0-4.0	Transit is between two and four times as expensive as auto
0.0	F	4.0+	Transit is more than four times as expensive as auto

Table 10 outlines the transit transfer and time perception LOS. Trips not needing a transfer are assigned LOS A, with each consecutive LOS involving one additional transfer, and LOS F entailing five or more transfers on the one-way journey to work. The time perception indicator was the ratio of the total transit time to perceived transit time.

<sup>22</sup> However, mode choice decisions for the work commute trip might be more likely to consider total automobile costs than trips for other purposes.

The perceived time was generated by applying the mode factors to each component of the transit journey in the TP transit trace (see Chapter 6 Transit Traces Methodology ).

Transforming the reconstituted ratio, effective trip time factors can be generated by taking the inverse of the scale (see Table 10b). A low scale value and a poor LOS indicate substantial burden associated with enduring waiting and suboptimal modes. In such situations, travelers are assumed to perceive the passage of time at a much lower rate than normal (defined as in-vehicle automobile travel time), resulting in a perception that more time has passed than the actual amount. The large mode factor is associated with such a state.

Table 10 Transfer and Time Perception Scales and Example LOS<sup>23</sup>

Scale	LOS	Transfers
1.0	A	0
0.8	B	1
0.6	C	2
0.4	D	3
0.2	E	4
0.0	F	5+

a) Transfer

Scale	LOS	Factor
1.0	A	1.0
0.8	B	1.3
0.6	C	1.7
0.4	D	2.5
0.2	E	5.0
0.0	F	large

b) Time Perception

The automobile trip chaining and schedule consistency indicators directly used percentages calculated in the dataset and reported in Chapter 10 (Trip Chaining and Convenience Measures). The sum of the component scores yielded a composite score for each case. Figure 34 ranks the commute cases in the final dataset by the composite score and illustrates the relative contribution of each. This information quantifies the likelihood of Commute Atlanta participants to switch to transit at the onset of congestion pricing.

<sup>23</sup> Note that while the time perception factors at discrete scale values are listed for explanatory value, the data are continuous.

The intent here is not to suggest individual measures should be summed to form a composite indicator. Rather, the exercise urges reflection on the factors involved and a means to display all simultaneously.

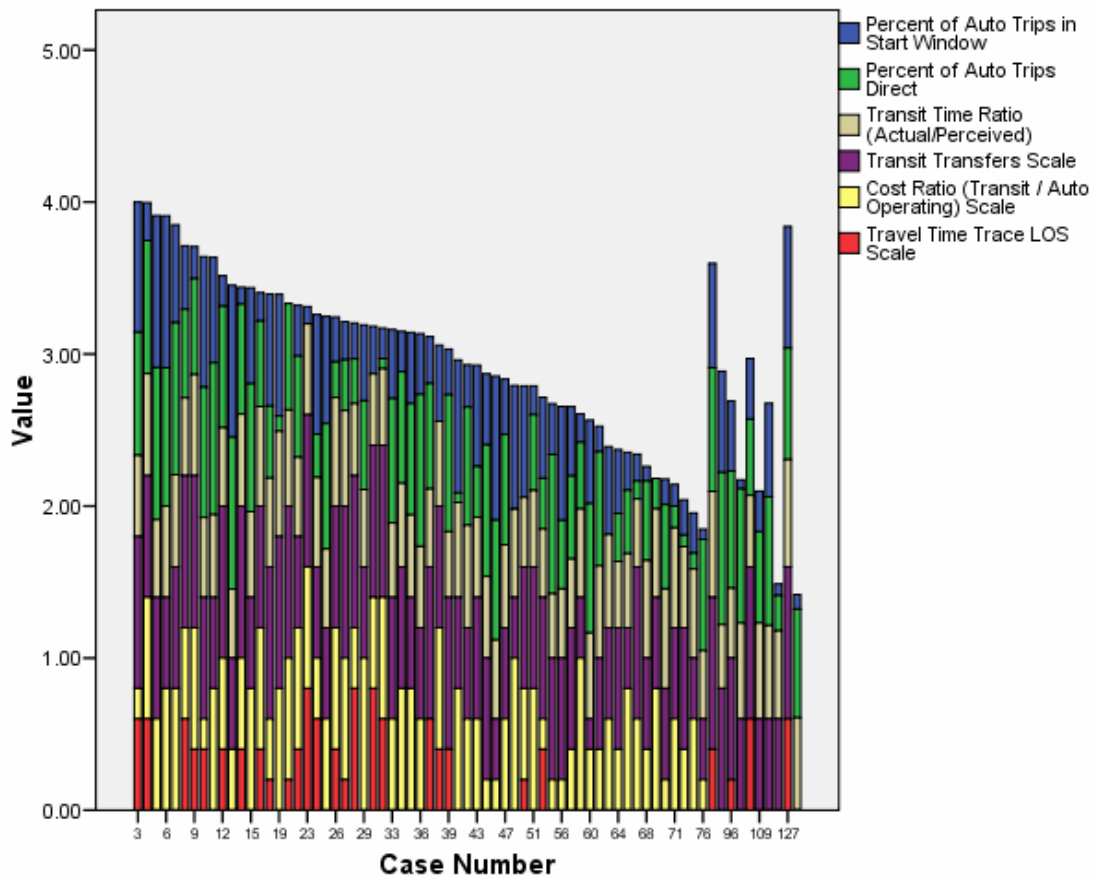


Figure 34 Composite Transit Attractiveness Scores

## **CHAPTER 13: IMPACTS OF ACTIVITY CENTERS AND OTHER GEOGRAPHIC IMPLICATIONS**

Application of the TCQSM LOS measures has often focused on activity centers (Xin, Fu, and Saccomanno 2005). Also, land use planning tools such as concentrating development in activity centers have attempted to address transportation problems and are therefore of interest. Thirty-nine of the 71 work locations were within activity centers: 31% in regional centers, 17% in city centers, 6% in town centers, and 1% in station communities. No “major” activity centers were involved. Two home locations were in regional centers, two home locations were in town centers, and one home location was within a station community.

Figure 35 displays a breakdown of the number of work locations contained within activity centers of various types. The total automobile trip sample of 136 cases is displayed as “unfiltered” and the 71 cases for which transit traces were found comprise the filtered results. The percentage of work locations not within activity centers for which a transit trace was not identified was higher than the percentage for work locations within activity centers (see also Figure 36a).

The difference between transit and automobile travel time for commuters who work in activity centers (see Figure 36b). The average difference between transit and automobile time for workplaces in activity centers was just under an hour compared to about an hour and a half for work locations not in activity centers.



Another major finding regarding activity centers is the improved composite transit attractiveness score relative to non-activity center locations (see Figure 37).

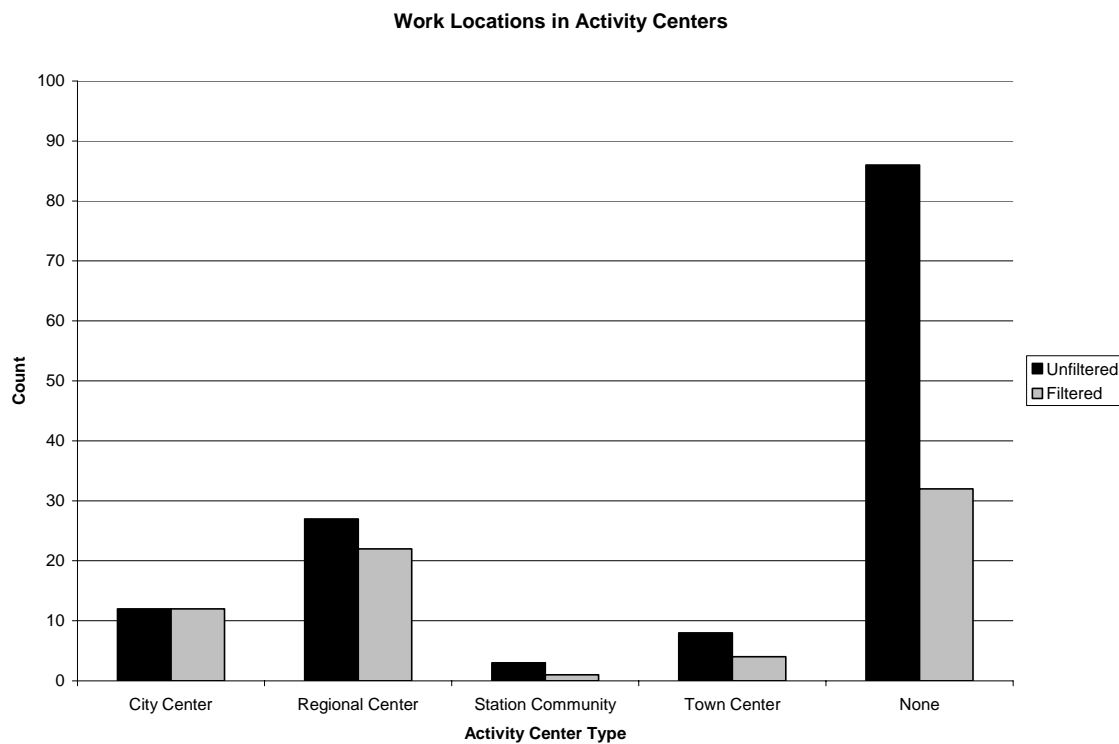
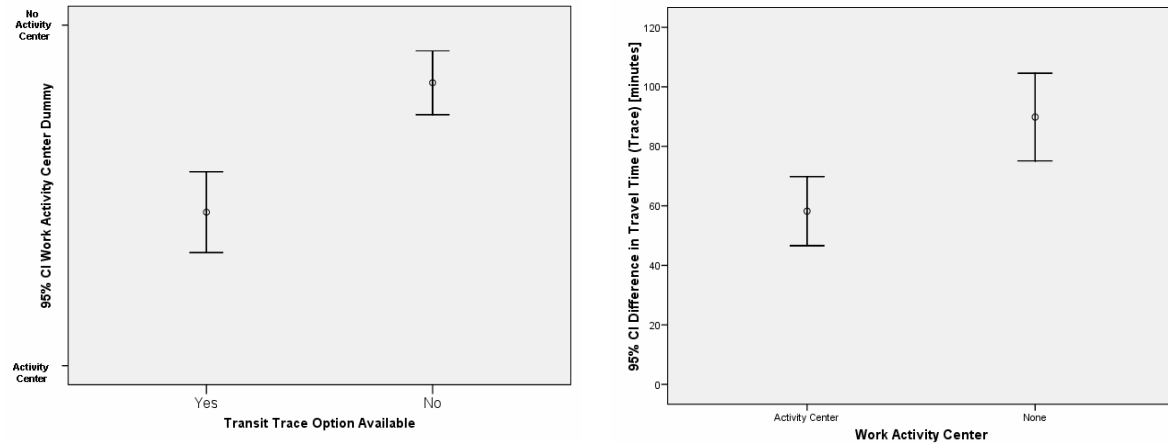


Figure 35 Work Locations in Activity Centers for Total Sample and Trace Results



a) Transit trace option

b) Travel time difference

Figure 36 Effect of Activity Centers

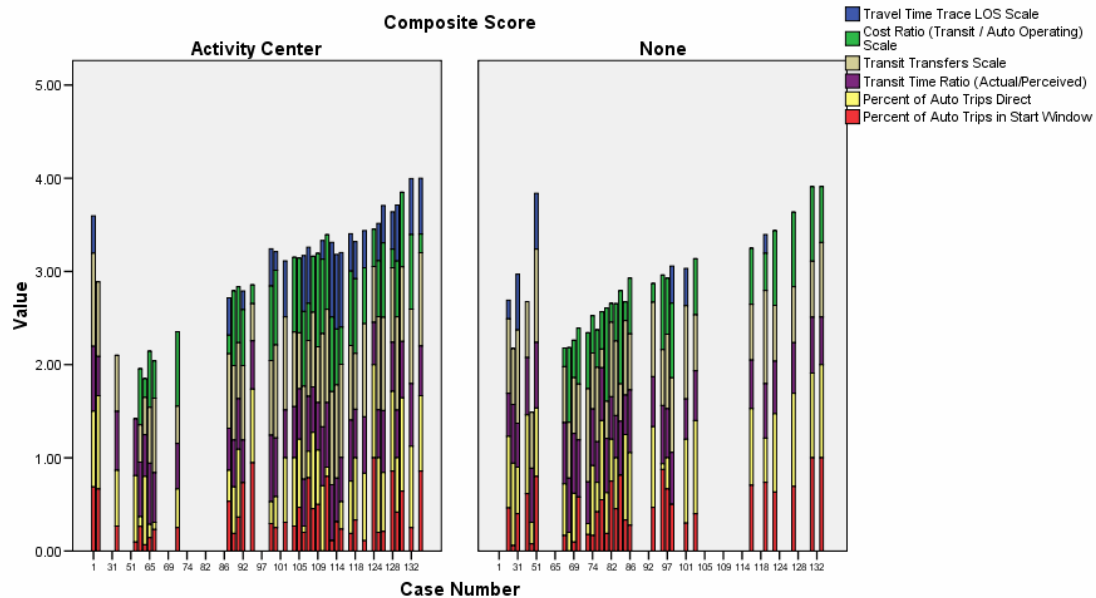


Figure 37 Composite Score for Transit Attractiveness by Activity Center

This is not so much as to hail activity centers as the savior of transit but to comment on the correlations between areas designated as activity centers and transit attractiveness. The relationship is not necessarily causal, but focusing planning and development attention in transit-rich locations is encouraging.

In addition to classifying commutes and investigating the relationship between activity centers and transit feasibility, this study draws geographic implications from cases for which no transit trace was found. The two relevant classes of cases are direct walk and no transit trace.

### **Direct Walk**

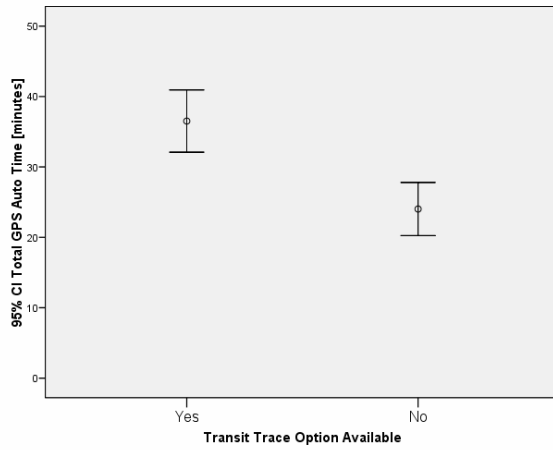
Because direct walk commutes did not utilize actual transit modes, they were not included in the bulk of the analysis. However, a note on their characteristics and “level of service” is included here. Five cases were identified: one was from an in-town neighborhood; three were in suburban areas close to interstates on the west, east, and northeast of the city, respectively; and the fifth was in a rural portion of a county to the northeast outside of any transit service area. The cases did not have common trip chaining behavior (the percentage of non-chained, direct trips ranged from 20 to 100 percent direct), and departure/arrival consistency varied among the five cases of direct walk (from 30 to 100 percent of the time within five minutes of the median time). Table 11 lists the Network-Analyst walking distance and time (see Section \_ Title) for each case. Subtracting the corresponding automobile trip time from the walking “transit” time yielded LOS measures. Walking up to 2.82 miles (LOS E) will not produce a LOS as low as the LOS F achieved by the majority of the transit traces that actually utilized transit.

Table 11 Direct Walk Case Summaries

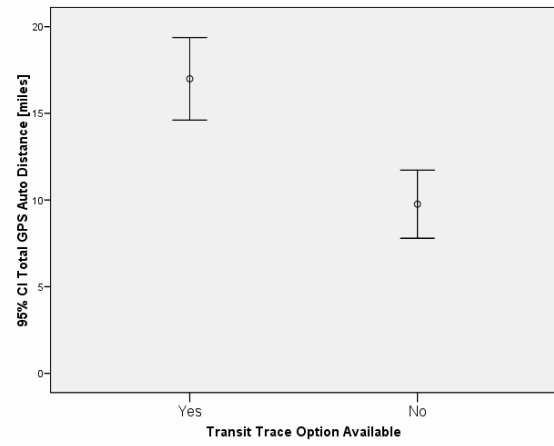
	Distance [miles]	Time [minutes]			LOS
	Walk	Walk	Auto	Difference	
1	2.82	56.5	9.5	47.0	E
2	0.60	12.0	5.8	6.2	B
3	1.81	36.3	11.2	25.1	C
4	0.25	4.9	4.6	0.4	B
5	1.35	26.9	5.4	21.6	C

### No Transit Trace

Thirty-six cases never produced a TP+ transit trace. A reason these trips did not have a transit option was the work location existing in zones not connected with walk support links. An additional 20 cases were classified as having no transit option because the transit options that were initially traced were found to be unreasonable (see Chapter 6 Transit Traces Methodology). Though no transit data were available for comparison, the automobile data are presented in Figure 38. The driving time was actually longer for commuters who had a transit option than those who did not. The 10-mile average distance for the no transit available cases does not seem impractically high to be served by transit. However, the issue is not simply the distance of the trips that need to be served, but the location of trip origin and destination relative to the existing transit network. The next chapter will take a step back from the highly customized perspective of the above analysis and address the regional service coverage area and transit supportive area.



a) Automobile time



b) Automobile distance

Figure 38 No Transit Trace

## **CHAPTER 14: SERVICE AREA AND TRANSIT-SUPPORTIVE AREA DETERMINATION**

The goal of the analysis reported in this chapter is to consider the regional context of Atlanta's transit system and to assess availability of transit service, the first prerequisite for transit service (TRB 2003). The service coverage area represents areas assumed to be within walk access to transit, using the standard quarter mile of bus and half mile of rail. In this analysis, every local and express bus stop<sup>24</sup> was buffered using a quarter-mile radius and each MARTA rail station was buffered using a half-mile radius. Pedestrian-inaccessible areas were not removed as the data required for identifying pedestrian access from the area adjacent to the route/stop (sidewalk access, crossing locations, etc.) are not currently available in the travel demand model. Hence, some transit stops are likely to be less accessible than reported herein.

Transit-supportive areas (TSAs) is the embodiment of the idea that transit only needs to be provided where there is sufficient density to support transit. From the TCQSM, the minimum densities required to support hourly transit service are three residential units per gross acre or four jobs per gross acre. Using this metric, transit-supportive areas in the 20-county Atlanta Metro<sup>25</sup> area were identified using transportation analysis zone (TAZ) level households and jobs density for the year 2005 data obtained from ARC.

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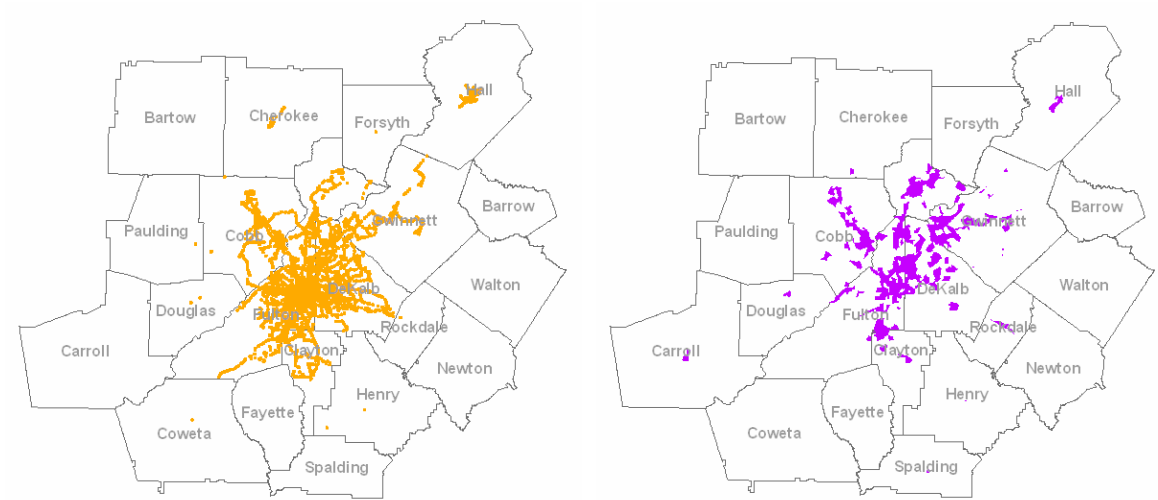
<sup>24</sup> Consistent with ARC methodology for determining walk access to transit (see Appendix [X](#)) and reflective of local bus service's high stop frequency, the buffers were applied to the shape points in addition to actual coded stops.

<sup>25</sup> [The 20-county region is the eight-hour ozone non-attainment area designated by EPA.](#)

The service coverage area was compared against the transit-supportive area using spatial analysis to determine the portion of the TSAs that is served and is not served by transit. The results indicated that 72% of the TSAs is served by fixed-route transit in the 20-county Atlanta Metro area, which yields a LOS C. The results are illustrated in Figure 39 and Figure 40.

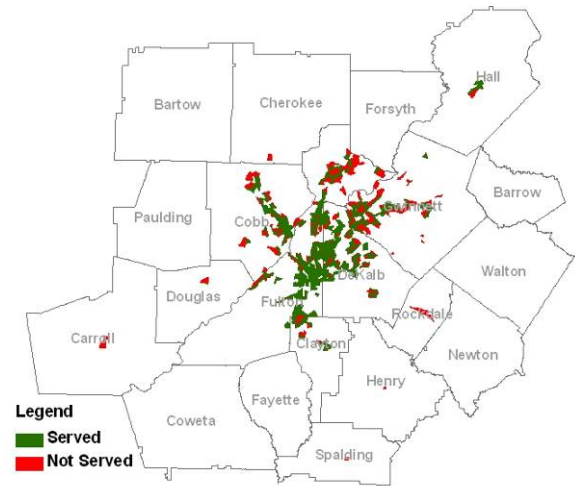
Atlanta's transit system does better on this measure than the difference in travel time. Figure 40 shows most of the central areas are transit-supportive and served by transit. Transit-supportive areas diminish in more suburban areas as does the percent of the transit-supportive areas served.

The service coverage LOS measure does not directly address the region's low density. Assuming a rough average of two persons per household, the TCQSM-recommended transit-supportive residential density of three households per gross acre would translate to six persons per acre. According to the ARC, the average population density in 2006 for the Atlanta metro area (10-county) was 2.06 persons per acre and most of the region's fastest growing suburban areas have densities lower than the region's median, 3.93 persons per acre. The service coverage LOS measure does not apply to the major growth areas in Atlanta because the transit-supportive area, as defined, excludes them. Atlanta's challenge is providing commute alternatives to commuters living in low-density neighborhoods that cannot support hourly transit service. This underscores the importance of infill development and channeling development into transit-accessible activity centers and devising creative strategies to provide transit service where feasible.



a) Metro Boundary and Transit Coverage Area

b) Metro Boundary and Transit-Supportive Areas



c) TSA Served and TSA Not Served

Analysis Area	Area (mile <sup>2</sup> )	% Area Served	LOS
20-County Metro Atlanta	6403.46		
Coverage Area	381.925		
Transit- Supportive Area	239.531		
TSA Served	173.349	72.4%	C

d) Fixed-Route Service Coverage LOS

Figure 39 Transit-Supportive Area



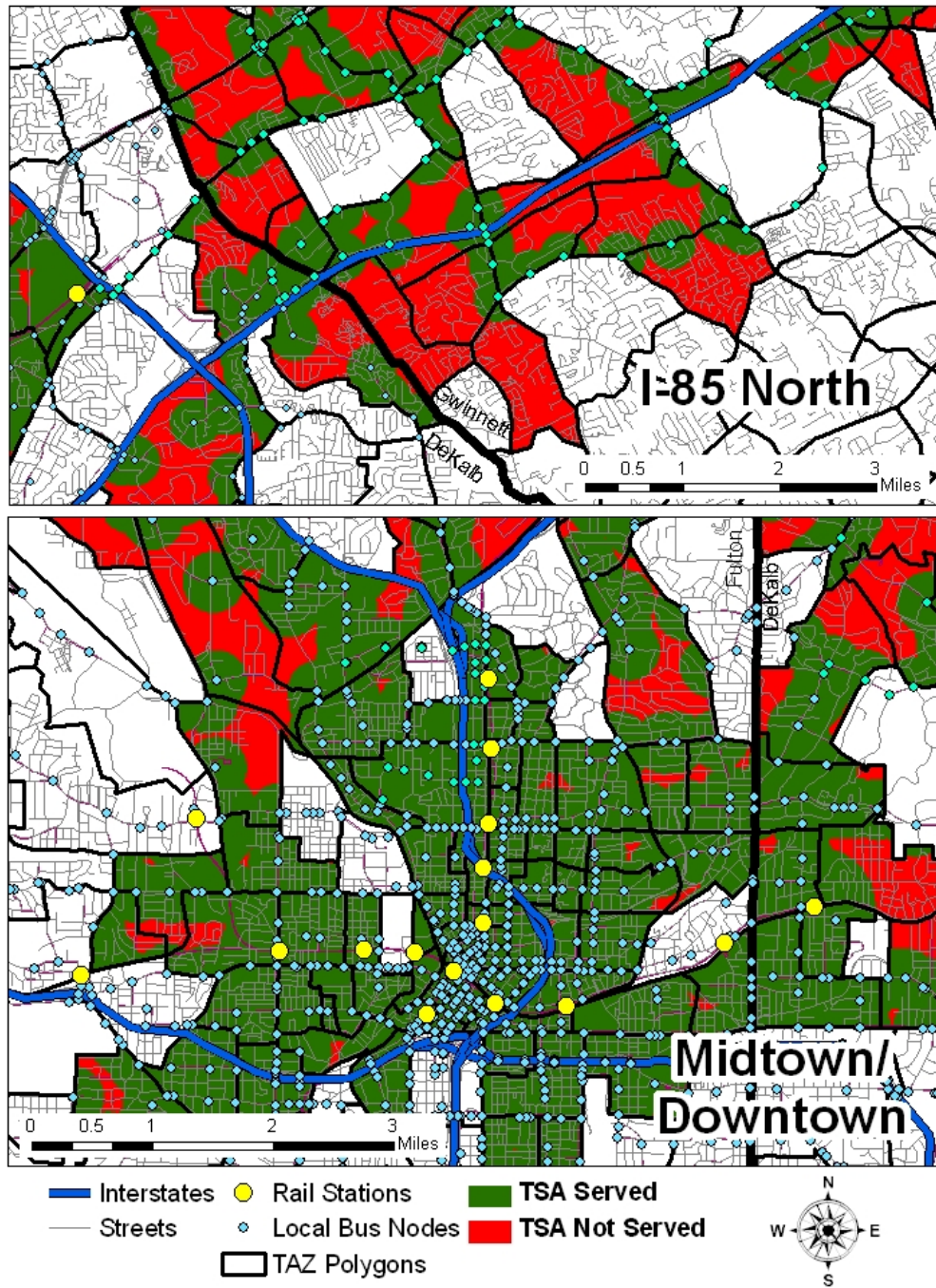


Figure 40 TSA Detail

## **CHAPTER 15: CONCLUSIONS**

This thesis compared revealed-preference automobile morning work commute trip data from GPS-instrumented vehicles of 136 participants of Commute Atlanta with their potential transit alternatives identified by performing skims and traces through the transit network in the regional travel demand model. The Transit Capacity and Quality of Service Manual (TCQSM) travel time level of service (LOS) measure for transit was applied to these GPS automobile and modeled transit data. Demand model travel time skims were also compared to both the revealed GPS travel time data and were also used to calculate the transit vs. modeled-automobile travel time LOS. Comparing the commute times from the various sources enabled not only comparison between automobile and transit modes, but model output and revealed commute travel behavior. In addition to transit travel time, additional variables that measure relative modal convenience were assessed, including number of transit transfers, perception of transit time, automobile schedule consistency, and automobile trip chaining. The relative monetary cost of commuting by each mode was also evaluated. In the last set of thesis analyses, TCQSM service coverage LOS was applied to the Atlanta region to quantify system-level transit availability.

The GPS-revealed automobile skims from home to work were 45% shorter than the model-reported skims from origin to destination zone. The skims are output from the travel demand model and are used to represent the time cost of traveling between zones by any given mode. The GPS data represent revealed travel times actually experienced by road users. In this study, the traces used the model transit network and input

parameters to run customized paths between zones. The trace results were screened to evaluate their reasonableness in representing individual travel behavior.. The transit traces were longer than the minimum modeled transit network skims by about 24%. Therefore, the attractiveness of the automobile mode may be under-represented and the attractiveness of transit may be overstated in the model. Additional research is needed to compare model output with individual traveler experience.

Only about 9% of commuters drove directly to work more than 95% of the time. Only about 6% of commuters left home within five minutes of their median departure time more than 95% of the time. Based on the model's assumptions with respect to time penalties for mode changes and waiting times, commuters perceive the total transit trip time as between being 1.25 and 2.5 as long as the actual (modeled) time. Only about 25% of commuters could take transit without having to transfer transit modes.

Transit needs to provide a high level of service along a path with activity-rich land and seamless access to enable commutes to trip chain with a level of convenience approaching that afforded by the automobile. Other factors affecting transit trip chaining include the ease of carrying goods and traveling with or dropping-off children. Additional research into trip chaining behavior of transit users and land use near transit is warranted. Future transit and household level travel surveys should be designed to assess transit alternatives, not just choices made by transit users.

The cost of driving to transit reduces the potential cost advantage of transit over driving to work. Considering automobile operating cost, roughly half the commutes were cheaper by automobile and half were cheaper by transit (parking is assumed to be free, which is reasonable for the vast majority of Atlanta commuters).<sup>26</sup> When considering the total automobile costs, automobile becomes much more expensive than transit, although commuters rarely consider the total cost in the individual trip decision. Automobiles can compete with transit on an operating cost basis in Atlanta, although the automobile cost advantage is not as stark as the advantages of time and convenience.

With regard to the Transit Capacity and Quality of Service Manual transit-automobile travel time LOS, researchers are strongly cautioned in attempting to use travel demand modeling results to evaluate transit system quality of service from the user perspective. The TCQSM service area LOS accessibility measure helped paint a regional picture of transit service in Atlanta. Transit service does connect the majority (72.4%) of transit accessible areas, as defined by TCQSM. However, the percentage of land comprising these transit supportive areas is only 3.7% of the region. The prevalence of very low density development in Atlanta limited the usefulness of the service area LOS. In addition, future work needs to consider drive-to-transit access mode in the determination of transit service area, which is currently outside the scope of the TCQSM method.

It is difficult to provide transit at a high level of service for extremely short trip. It is unreasonable to expect transit service be provided for trips of any length for all areas.

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<sup>26</sup> According to the Atlanta Employer Commute Options Survey, 86% of companies surveyed in the Atlanta metro area provide free parking to their employees. See Zuehlke and Guensler (2007) for more information on the survey.

Conversely, transit cannot be expected to be provided in outlying portion of the region, which is what the transit-supportive area concept addresses. However, the reality of development in the Atlanta region is that the vast majority of the public lives in that 96.3% of the region where land use densities do not support transit use according to the traditional definition. The sample used in this study, Commute Atlanta participants who were in fact already driving and not taking transit, is indicative. Any analysis of commute mode choice in Atlanta must take the land use element into consideration and recognize the implications that walkable transit is not an option and is unlikely to become an option for much of the population if current land use development patterns and densities continue and the TSA measure guide future transit placement. Nevertheless, there is a portion of the driving population that does have a walkable transit option or one within a reasonable drive, and efforts should be made to target these populations.

Additional work is necessary to refine methods of evaluating the relative costs of transit and driving. For example, including other externalities and aspects of the commute mode choice decision can help strengthen the analytical toolset. Travel models need to incorporate methods that refine model sensitivity to individual travel experience, walk access in particular. Work should continue on developing ways to evaluate the quality of transit service. Transit's subservience to the automobile should not be a given. A study of quality bus corridors in Dublin, Ireland achieved mostly travel time LOS A and B (Caulfield and O'Mahony 2004) for the routes services, but again land use patterns are different in Dublin than they are in Atlanta. This indicates providing quality transit service that is competitive with the automobile is possible where land uses are aligned

with transit service, but will also require improvements in transit user experience of travel time, convenience, and cost.

## **APPENDIX A**

### **WALK ACCESS DISCUSSION**

Walking is involved in TDM models in transit access and egress representation. These links are involved in impedance determination, path building, and trip assignment. Analysts are challenged with coding transit access in models of transportation networks to reasonably represent reality. To aid calculation, disaggregate individual travel behavior is represented at the aggregate level, which can result in a single walk-to-transit impedance value for each zone.

The ARC model represents transit walk access by logically splitting zones into different mode-based market segments. The split is binary into walk and non walk portions. Trips associated with non-walk portions of zones can utilize park-and-ride and/or drive-to-transit. The walkable portions are determined by a straight line distance criterion to transit stops. A 0.125 mile by 0.125 mile grid is overlaid with the TAZ and stop locations. Each grid point is associated with a TAZ. If the closest transit stop to each grid node is within 0.4 straight miles, then the grid node is considered accessible to transit by walk. The distances between all transit accessible grid nodes and respective closest transit stop are summed for each TAZ to produce an average walk distance to transit. Applying a uniform walk speed of 3 miles per hour, the single walk access impedance value for each TAZ is generated and applied to all walk-to-transit support links.

Though a reasonably typical method of representing walk access to transit within regional travel demand forecasting models, this method has some shortcomings. The average representation is incongruous with variable and unique path impedances for individuals skimming the network, as has been noted in the literature: “No single, simple representation of a ‘walk link’ to transit can reflect the impedance perceived by residents of a traffic zone” (Associates 1998) and “Walk times from zone centroids to transit nodes mask important variations in actual walking time” among individuals (Staff 1997). Further, the zonal representation, even if split into walkable and non-walkable portions, cannot account for non-uniform distributions of land use and trip generation within zones.

In addition to complicating walk access representation, using an aggregated zonal framework to represent individual accessibility can cause several problems. Such a treatment ignores differences among individuals and their personal idiosyncrasies and perception of the geographical and temporal availability of urban opportunities (Kwan and Weber 2003). Additionally, zonal models are generally incapable of handling intrazonal trips or “self-potential” (Kwan and Weber 2003). The aggregated nature of TDM models yields insufficient sensitivity to accurately treat the spatial delicacy of walk access to transit.



## **APPENDIX B**

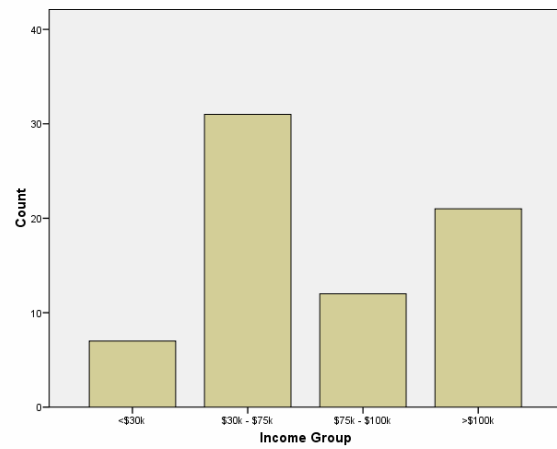
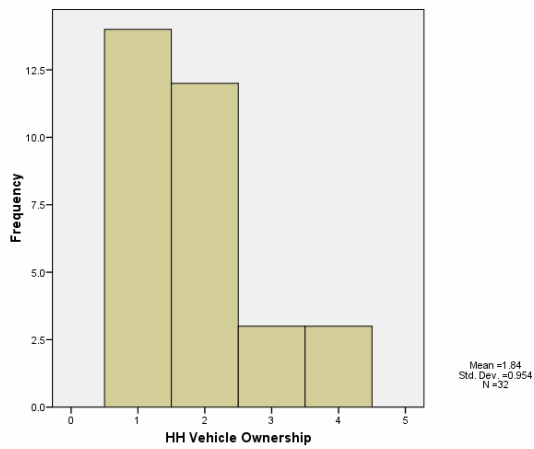
### **DEMOGRAPHIC CHARACTERISTICS OF THE SAMPLE**

Demographic data were available on Commute Atlanta participants via the household travel diary survey effort. The final sample was comprised of an even 36 males and 35 female. Figure \_\_ presents the distribution of the sample into age groups. The largest age group was 46-55, with 26 drivers, or about 37% of the sample. About 40% of the drivers (29) were in the 26-45 age group. Most of the remaining participants were over 56 (15, or about 20%). Ethnicity data were available for only a limited subset of the sample (31 of the 71). Of these, 71% were Caucasian, 26% were African American, and 3% were Latino.

In addition to data on individual Commute Atlanta participants, data were available at the household level. Most households owned one or two vehicles (see Figure 41a). Figure 41b presents the income groups of the sample. The most common income group is \$30-75,000 per year (44% of the sample), followed by more than \$100,000 per year (30% of the sample)<sup>27</sup>. The household size distribution is given in Figure 41c. The most common household size was two persons (23 of the drivers), followed by single-person households (16 drivers), and three-person households (14 drivers), with a decreasing share of larger households. Most drivers belonged to households with one or two workers (see Figure 41d), and the majority of households had no children (see Figure 41e).

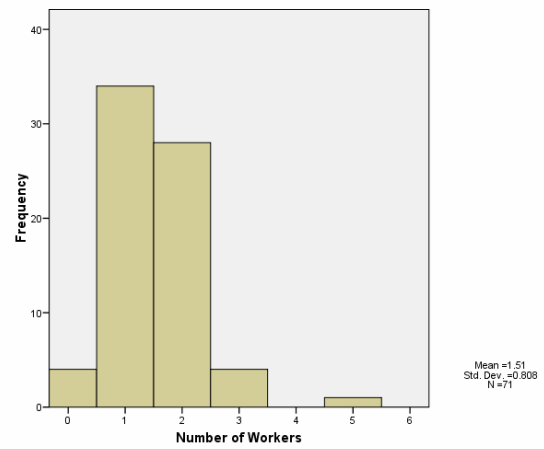
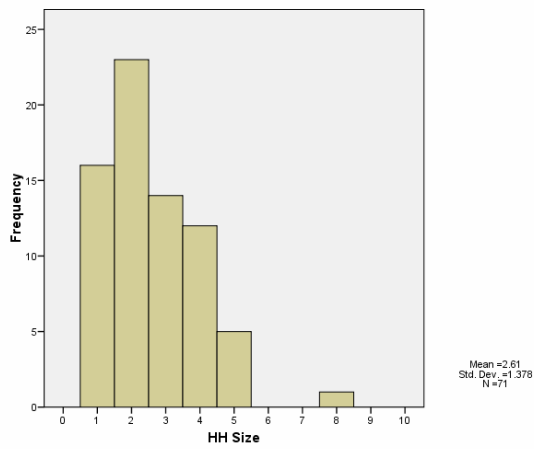
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<sup>27</sup> The Commute Atlanta sample is under-represented by low income households for a variety of reasons as outlined in Ogle, et al., 2005.



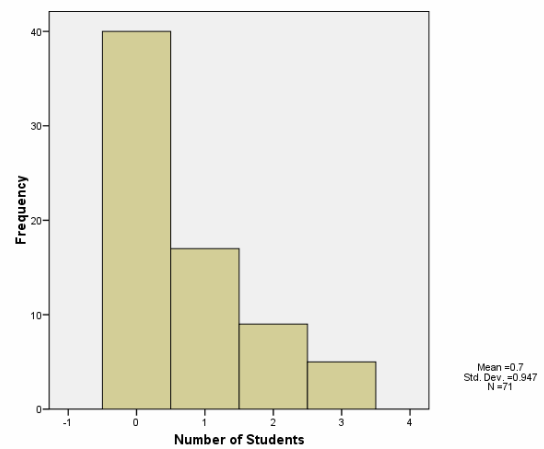
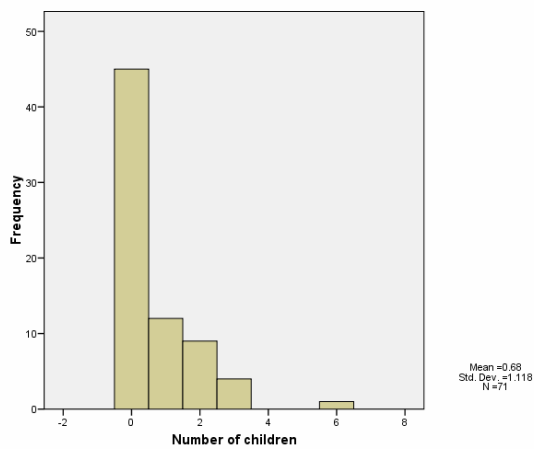
a) Vehicle Ownership

b) Income Group



c) Household Size

d) Number of Workers



e) Number of Children

f) Number of Students

Figure 41 Household Demographic Characteristics of the Final Sample

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